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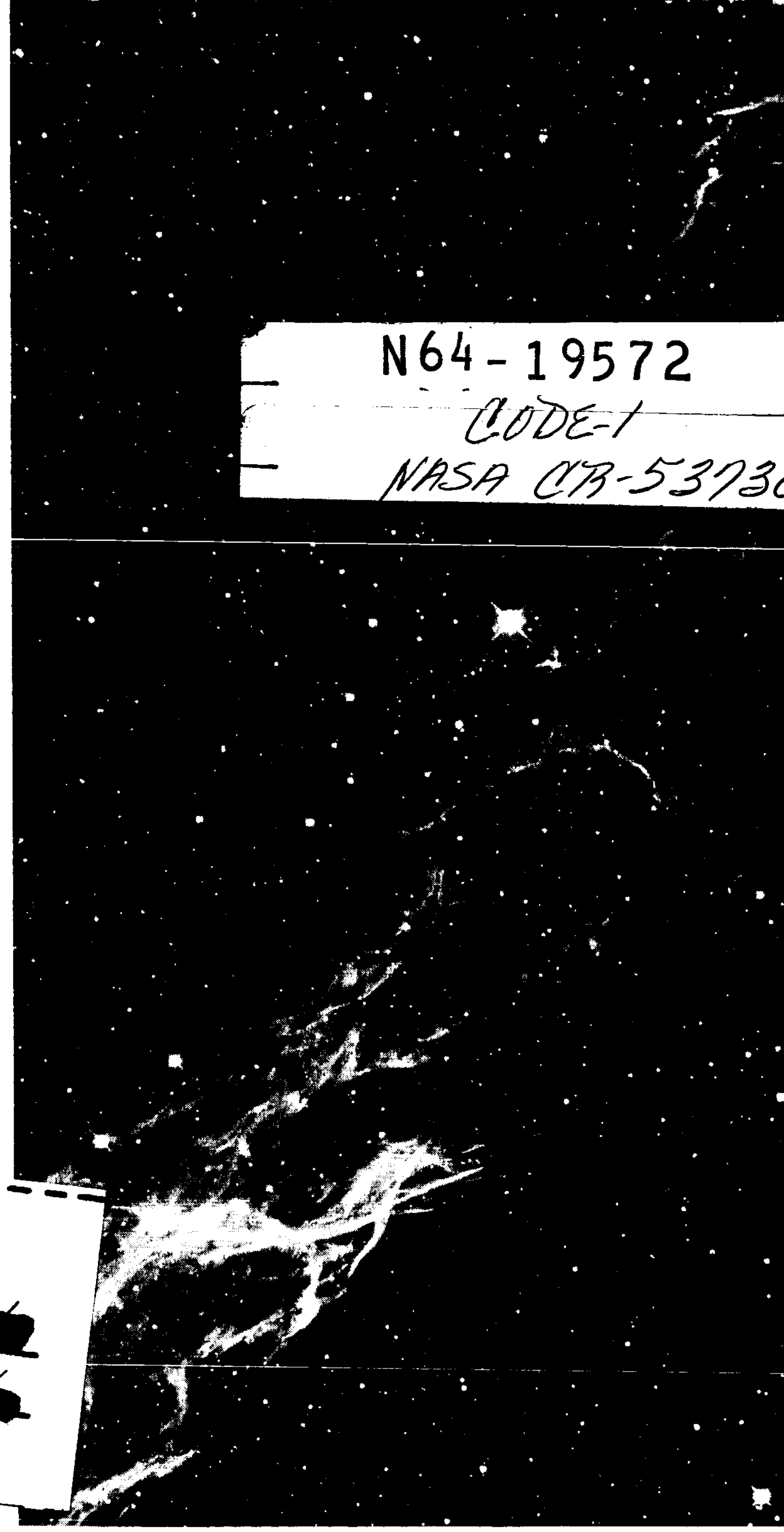

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Report No. T-4R

# SUMMARY OF ONE WAY BALLISTIC TRAJECTORY DATA: EARTH TO SOLAR SYSTEM TARGETS

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Title

# SUMMARY OF ONE WAY BALLISTIC TRAJECTORY DATA: EARTH TO SOLAR SYSTEM TARGETS


by

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Lunar and Planetary Programs
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(NASA Contract ~~No~~ NASr-65(06))


APPROVED:

L. Reiffel, Director

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ABSTRACT

## SUMMARY OF ONE WAY BALLISTIC TRAJECTORY DATA: EARTH TO SOLAR SYSTEM TARGETS

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A survey of one way ballistic trajectories (conic sections, impulsive thrusting, one gravitating body at a time) to major targets and positions within the solar system has been generated using the ASC/IITRI Conic Section Trajectory system on the IBM 7090 computer. This survey was prepared to support the broad studies of scientific objectives, mission requirements, mission success probabilities and mission cost for solar system exploration being carried out under Contract No. NASr-65(06) by the Astro Sciences Center. This report allows one to readily compare energy requirements for flights to a very wide variety of places within the solar system. Curves are presented for Ideal Velocity ($\Delta V$) and Hyperbolic Excess Speed at the Target (VHP) for flights to all the planets, together with a table of the corresponding communications distances. Curves of $\Delta V$ for flights from Earth to distances of 0.01 AU to 100 AU in the ecliptic plane are presented. Four curves are given for flights out of the ecliptic plane to distances of 0.3 to 5.0 AU from the Sun, including flights to points directly over the Sun. A curve is presented of the key parameters for minimum energy flights to all angles out of the ecliptic plane. Finally, curves and tables of the Velocity Increments (DV) required to put approaching

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spacecraft into near planet orbits, including orbits similar to satellite orbits, are presented for all the planets. These curves are valid for altitudes above which there are no atmospheric effects on the trajectory.

Author

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# SUMMARY OF ONE WAY BALLISTIC TRAJECTORY DATA: EARTH TO SOLAR SYSTEM TARGETS

## 1. INTRODUCTION

This report gathers into one reference document the basic parameters governing one way ballistic trajectories to targets throughout the solar system. The data in this report for trajectories to the planets, and to positions in and out of the ecliptic plane, allow one to estimate in a uniform manner the requirements for a wide variety of interplanetary flights. All trajectories were computed by the ASC/IITRI Conic Section Trajectory system on the IBM 7090 computer (Pierce, Narin 1964). The primary data generated by this system which are used in this report are ideal velocity $\Delta V$, hyperbolic excess speed at the target VHP, communications distance RC, and the velocity increment DV for transfer from a target approach hyperbola into an orbit around a planet. These quantities are defined at the end of this section, with a few other quantities of special interest.

The first three of these quantities, $\Delta V$, VHP, and RC, are covered in Section 2 of this report for all of the planets in the solar system.

Section 3 shows the velocity requirements for flights, in the ecliptic plane, to targets located from 0.01 to 100 AU from the Sun. This section includes both Hohmann and non-Hohmann transfers.

Section 4 shows the velocity requirements for flights to distances R from the Sun of 0.3 to 5 AU, and to a range of distances Z above the ecliptic plane from 0 to R, i.e., flights from Earth to targets at fixed distances from the Sun but at positions ranging from in the ecliptic plane to directly above (or below) the Sun. This section also summarizes the minimum energy trajectories which will place a spacecraft at a given angle out of the ecliptic plane.

Section 5 then covers near planet maneuvers, at altitudes above which there are no atmospheric effects on the trajectories. The figures there, plus the supplementary tables, should cover almost all cases of interest. Specifically included are orbits which are similar to those known for the satellites of all the planets. In this section the atmospheric densities for all the planets are estimated.

The definitions referred to previously are the following:

1. Ideal Velocity $\Delta V$, the total velocity increment which must be given to a spacecraft on leaving Earth:

$$\Delta V = \sqrt{(36,178)^2 + (VHL)^2} + 4000 \text{ ft/sec}$$

Here 36,178 ft/sec is the characteristic velocity for Earth escape, launching from Cape Kennedy, and 4000 ft/sec is a correction for gravitational and frictional losses during launch. VHL is launch hyperbolic excess speed defined below.

2. Launch Hyperbolic Excess Speed, VHL, the difference between the spacecraft's heliocentric velocity after Earth escape and the Earth's velocity in its orbit at the same time.

3. Hyperbolic Excess Speed at the Target, VHP, the spacecraft to target velocity difference at arrival time.

4. Communications Distance, RC, the distance between launch body and the target at time of arrival of the spacecraft at the target.

5. The Velocity Increment, DV, required to transfer a spacecraft from its target approach hyperbola into an orbit around a target.

6. The Heliocentric Central Angle, HCA, the angle between the position vector of the launch planet at time of launch of the spacecraft and the position vector of the target planet at time of arrival of the spacecraft.

## 2. TRAJECTORIES TO THE PLANETS

Figure 1, 1967 launches to Mercury, is included to illustrate the properties of many of the curves in this report. The curve for time of flight TF = 85 days shows the ideal velocity required for 85 day flights to Mercury, launching between the end of November and the end of December in 1967; note that this is a constant time of flight curve, and the dotted line "A" on the figure corresponds to the requirement for a 15 day launch window for this time of flight. The other curves, for 95 through 125 day flights, are also constant time of flight curves. The dashed curve is a minimum energy curve; for any launch date the minimum $\Delta V$ required for a flight to Mercury launching on that date lies on this curve. Note that the time of flight varies along this line. In essence the minimum energy curve is the envelope of the constant time of flight curves. For all of the planets except Mercury the $\Delta V$ requirement for launches with 30 day launch windows along constant time of flight curves differs insignificantly from launches along the minimum energy curve. It is the constant time of flight points which are plotted in Figures 2 and 3. For Mercury, because of its rapid motion around the Sun and 7 degree inclination to the ecliptic plane there is a significant difference between launching along the minimum energy curve and along constant time of flight curves. For this reason there are 2 curves for Mercury in Figure 2.

Note the peaks shown in the 125 day and 115 day time of flight curves on Figure 1. These peaks occur when (1) the given time of flight and launch date correspond to a flight of approximately 180° (in heliocentric central angle HCA) and (2) the target planet lies slightly out of the ecliptic plane. When both these conditions are satisfied the only possible ballistic trajectory is a high energy highly inclined one, that is, the spacecraft must fly over the Sun, since for a 180 degree flight angle the plane containing the Earth, Sun and target planet is normal to the ecliptic plane if the planet is slightly out of the ecliptic plane.

Figures 2 and 3 show the minimum velocity requirements vs. time of flight for launches to the planets. For all curves, $\Delta V$, the ideal velocity shown for a given time of flight, is sufficient for launch anytime within a 30 day launch window; note that the requirement for a 30 day launch adds a small amount to the minimum $\Delta V$ corresponding to optimal launch time. This amount is typically about 1 km/sec in VHL, the right hand axis of Figures 2 and 3. In all cases launches are assumed to occur during the launch minima, which occur at intervals of slightly longer than one year (once per synodic period) for the outer planets.

For the outer planets, since there is a slight year to year variation in flight parameters as the planets move in their elliptical orbits, the curves are within $\pm$ 0.5 km/sec in VHL of the calculated values over the (launch) time intervals stated; for example flights to Saturn become somewhat more favorable later in the century, but over 1965 to 1980 lie within $\pm$ 0.5 km/sec of the given curve.

The curves on Figure 3 were calculated for 1975 launches; for the very long times of flight to Pluto the minimum $\Delta V$ occurs as Pluto is rapidly passing through the ecliptic plane in the year 2018. Launches to Pluto, arriving in 2018, will be relatively low energy for rather wide limits in times of flight and launch date. For Uranus and Neptune, which have relatively low inclinations, Figure 3 is valid for a reasonably wide range of launch dates, similar to those of Figure 2.

The table of communications distances on Figure 2 covers the data ranges indicated on the figures. As an example, for Jupiter RC is minimal at 4 to 4.5 AU for 500 day flights, and about 1 AU higher for 800 day flights.

Figure 4 shows the spacecraft hyperbolic excess speed at the target vs. time of flight for flights corresponding to Figure 2. For example from Figure 2 an 800 day flight to Jupiter, launching in 1970 to 1975, would require a $\Delta V$ of 50,000 ft/sec, and from Figure 4 the spacecraft hyperbolic excess speed at Jupiter would be about 6.7 km/sec.

Some caution should be exercised in using Figure 4 for the inner planets, since the VHP values for a given time of flight vary considerably over the launch window. For example 100 day flights to Venus launching on June 10 and June 30 of 1967 have $\Delta V$'s of 42,306 and 42,272 respectively, essentially the same, while for these two flights VHP's are 7.5 and 4.4 km/sec respectively. The points plotted on Figure 4 are typical values during the launch windows. For Mercury, because of its rapid motion, the variations are very large and it is essentially impossible to consider VHP except on a day to day basis. The range of VHP for Mercury, corresponding to the flights on Figure 2, would be 10 to 50 km/sec. For 200 day flights to Mars the VHP range for the 30 day 1967 launch window is 6.4 to 4.7 km/sec. For 700 day flights to Jupiter in 1970 the range of VHP is only 8.2 to 7.8 km/sec, and for the outer planets the VHP ranges are even smaller.

## 3. TRAJECTORIES IN THE ECLIPTIC PLANE

Figure 5 shows $\Delta V$ for flights in the ecliptic plane vs. time of flight. Note that for flights toward the Sun there is a sharply defined minimum energy for specific times of flight. All of the curves on Figure 5 were generated by placing, in the 7090 codes, a dummy target in a circular orbit at the given distance from the Sun, and calculating the velocity required to reach the target for various Earth-target launch geometries. The minimum velocity for each time of flight is plotted on Figure 5. For example, to reach 2 AU from the Sun in 200 days a $\Delta V$ of 45,000 ft/sec is required; note that the spacecraft would still have a considerable velocity at 2 AU and would continue out from the Sun for some additional distance.

Figures 6 and 7 show $\Delta V$ and time of flight TF for Hohmann transfers* from the Earth to distances of 0.1 to 100 AU from the Sun. These are the minimum energies required to reach the given distances from the Sun. Thus to fly a spacecraft to 5 AU requires, from Figure 6, at least 50,000 ft/sec ideal velocity; from Figure 7 this minimum ideal velocity flight of 50,000 ft/sec will take 950 days. The Hohmann trajectories of Figures 6 and 7 correspond to the minima of the curves on Figure 5.

Table 1 summarizes the key parameters for the 0.1 to 10 AU minimum energy flights shown in Figure 5.

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* A Hohmann transfer from one circular orbit of radius $R_1$ to another, coplanar circular orbit of radius $R_2$ is a flight in an elliptical transfer orbit such that the spacecraft orbit is tangential to the circle of radius $R_1$ at departure and tangential to the circle of radius $R_2$ at arrival. The transfer angle HCA is 180 degrees. The energy required for this type of transfer is the minimum energy required for transfer from a circular orbit of radius $R_1$ to an orbit touching a circular orbit of radius $R_2$.

## 4. TRAJECTORIES OUT OF THE ECLIPTIC PLANE

Figures 8, 9, 10 and 11 show the $\Delta V$ for flights to dummy targets at radial distances R of 0.3, 1, 2, and 5 AU from the Sun and in positions ranging from in the ecliptic plane to normal to the ecliptic plane; that is, the targets lie on an imaginary heliocentric sphere (with equator in the ecliptic plane) at various distances above the ecliptic. Thus a flight to Z = 5 AU, R = 5 AU is a flight to a point with celestial latitude $\beta$ of $\pm$ 90 degrees, directly above or below the Sun's center and normal to the ecliptic plane.

From Figures 2 and 3 for the planets, Figure 5 through 7 for flights in the ecliptic plane, and Figures 8 through 11 for flights out of the ecliptic one can compare the energy requirements for flights to a very wide variety of places within the solar system. Figures 8 through 11 and the ability to easily generate these for any R and Z, are characteristic of the flexibility of the ASC/IITRI Conic Section Trajectory system. The somewhat pronounced bumps in Figures 8 through 11 for out of the ecliptic trajectories are due to the problem of flying over the Sun, as discussed in Section 2 for the planets.

Figure 12 summarizes the minimum energy flights to reach any given celestial latitude $\beta$, that is, the minimum energy required to fly to $\beta$ degrees out of the ecliptic plane. For example, to fly to 30 degrees out of the ecliptic, that is, to a celestial latitude of 30 degrees, the Figure 12-A shows that the minimum energy flight requires a $\Delta V$ of 65,000 ft/sec; Figure 12-B shows that the flight time would be 85 days, and Figure 12-C shows that the spacecraft would intersect the 30 degree line at a distance of 0.75 AU from the Sun.

Figures 13 and 14 are included for reference, and relate $\Delta V$ to VHL and $C_3$. It should be noted that $C_3$ is simply VHL squared and multiplied by $10^6$, i.e. a $\Delta V$ of 50,000 ft/sec = a VHL of 8.66 km/sec = $C_3$ of $0.75 \times 10^8$ $m^2/sec^2$.

## 5. NEAR PLANET MANEUVERS

Figures 15 and 16 show the velocity increment DV required to transfer from an approach hyperbola to a capture orbit around the planets vs. VHP, the hyperbolic excess speed at the planet. This curve is obtained by assuming that a single thrust is applied at the perigee of the incoming hyperbola to alter the trajectory to an elliptical one with the same perigee. This is optimal use of the thrust. Specifically the equations are

$$(V_h)_{Per} = \sqrt{K\left(\frac{2}{R_p} + \frac{VHP^2}{K}\right)} \tag{1}$$

$$(V_e)_{Per} = \sqrt{K\left(\frac{2}{R_p} - \frac{1}{A_e}\right)} \tag{2}$$

where $(V_h)_{Per}$ is the speed at the assumed perigee distance $R_p$ from planet center, of the spacecraft with hyperbolic speed of approach VHP, and $(V_e)_{Per}$ is the speed of the spacecraft at the same position and in an elliptical orbit of semi-major axis $A_e$; that is $(V_e)_{Per}$ is the speed after the velocity increment is applied. Thus

$$DV = (V_h)_{Per} - (V_e)_{Per} \tag{3}$$

Note that

$$A_e = \frac{R_p + R_A}{2} \tag{4}$$

where $R_A$ = apogee distance for the capture ellipse. If we assume a circular orbit, $R_p = R_A$ and $A_e = R_p$ and then (3) becomes

$$DV = \sqrt{K\left(\frac{2}{R_p} + \frac{VHP^2}{K}\right)} - \sqrt{K/R_p} \qquad (5)$$

Note that for apogee altitude $Z_A \ll R_p$, DV is independent of $Z_A$; thus the upper altitude limit of validity of Figures 15 and 16 is that $Z_A \ll R_p$. The lower altitude limit of validity of Figures 15 and 16 is that the perigee altitude $Z_p$ be high enough for the spacecraft not to interact with the planetary atmosphere.

The altitudes at which planetary atmospheres become significant, from the point of view of spacecraft flight, can be roughly approximated by assuming a set of planetary atmospheric pressures, molecular weights and temperatures, and that the planetary atmospheres are isothermal. Then the atmospheric density profiles can be computed. For an isothermal planetary atmosphere the density $\rho(Z)$ is given by

$$\rho(Z) = \rho(o)\, e^{-\beta Z} \quad g/cm^3 \qquad (6)$$

where Z is the altitude above the planet's surface, $\beta$ is given by

$$\beta = \frac{Mg}{RT} \quad cm^{-1} \qquad (7)$$

where M = Mean molecular weight of atmosphere, g/mole

g = Gravitational acceleration of the planetary surface, $cm/sec^2$

T = Atmospheric temperature, °K

R = Gas constant = $8.314 \times 10^7$ erg/deg-mole and $\rho(o)$ is given by

$$\rho(o) = \frac{MP}{RT} \quad g/cm^3 \tag{8}$$

where P = planetary atmospheric pressure at the surface in dynes/$cm^2$, 1 atmosphere = $1.01 \times 10^6$ dynes/$cm^2$, and M, R and T are as defined before. Furthermore if we assume that the upper altitude limit for atmospheric effects is that altitude at which the planet's atmospheric density is equal to the Earth's atmospheric density at 100 nautical miles altitude, i.e., $5.37 \times 10^{-13}$ g/$cm^3$ (U. S. Standard Atmosphere, 1962), then the problem is solved. Table 2 summarizes these results. As can be seen from the table the range of validity of Figures 15 and 16 is, for all planets except Mercury, Pluto and Venus, from altitudes of perigee $Z_p$ greater than 200 to 400 km to apogee altitudes $Z_A \ll R_o$, where $R_o$ is the planet's radius. For Mercury which presumably has no atmosphere the figures are valid down to the planet surface. For Pluto there is no data at all. For Venus the perigee altitude must be greater than 400 to 500 km. Table 3 presents key planetary data for reference purposes.

Note also that for very large orbits around the planets, as $R_p \rightarrow \infty$, DV $\rightarrow$ VHP. This is a good approximation for VHP's of 25 km/sec or larger for almost all $R_p$.

A comparison of the DV vs. VHP curves for Mercury and Jupiter in Figures 15 and 16 shows that it is very much easier to go into a near planet orbit around Mercury than around Jupiter for low values of VHP.

Tables 4 through 11 show, for all the planets, the velocity increment DV which must be applied to an incoming spacecraft to put it into parabolic and circular orbits of perigee 2, 5, 10, 35 and 100 planet radii from the planet center. The basic assumption for these tables is the one used before: the single thrust is applied at the perigee of the incoming hyperbola to alter the trajectory to a parabolic or circular one with the same perigee.

Note that for the massive planets Jupiter, Saturn, Uranus and Neptune, the velocity increments required to go into parabolic orbits are less than those for the smaller planets. Again comparing Jupiter and Mercury it is significantly easier to go into a parabolic orbit around Jupiter than around Mercury, although the reverse is true if one is going into a near planet mapping type orbit.

It should be noted that the parabolic orbit is the limiting case of a highly eccentric elliptical orbit; thus the velocity increments in Tables 4 through 11 are valid for highly eccentric elliptical orbits with the perigees given in the tables.

Table 12 is included for its reference value, and shows the orbital periods for spacecraft in circular orbits at 2 to 200 planet radii for all the planets.

Figures 17 through 28 show the DV required to go into orbits matching those of the satellites of the planets vs. VHP. Note that, as before, the velocity increment DV is assumed to be applied at the perigee of the planetary approach hyperbola. Furthermore, implicit in these figures is the assumption that the spacecraft approaches the planet in a plane containing the satellite orbit. In Figures 17 through 28, where more than one object is associated with a given curve, the individual object curves are identical to within the thickness of the line. Table 13 lists the key data for the satellites of the planets.

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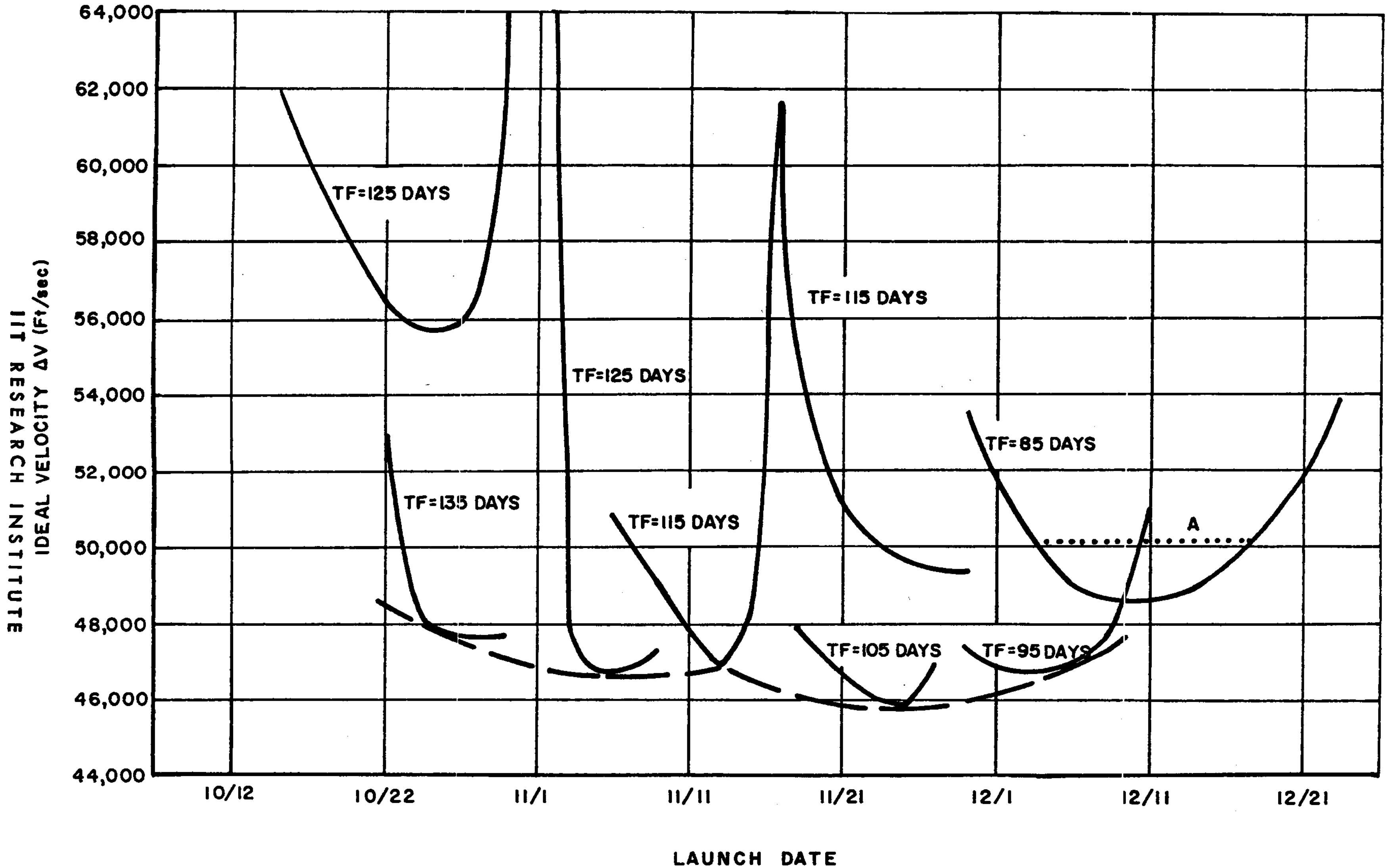


Figure 1 1967 Launches to Mercury: Ideal Velocity Vs. Launch Date

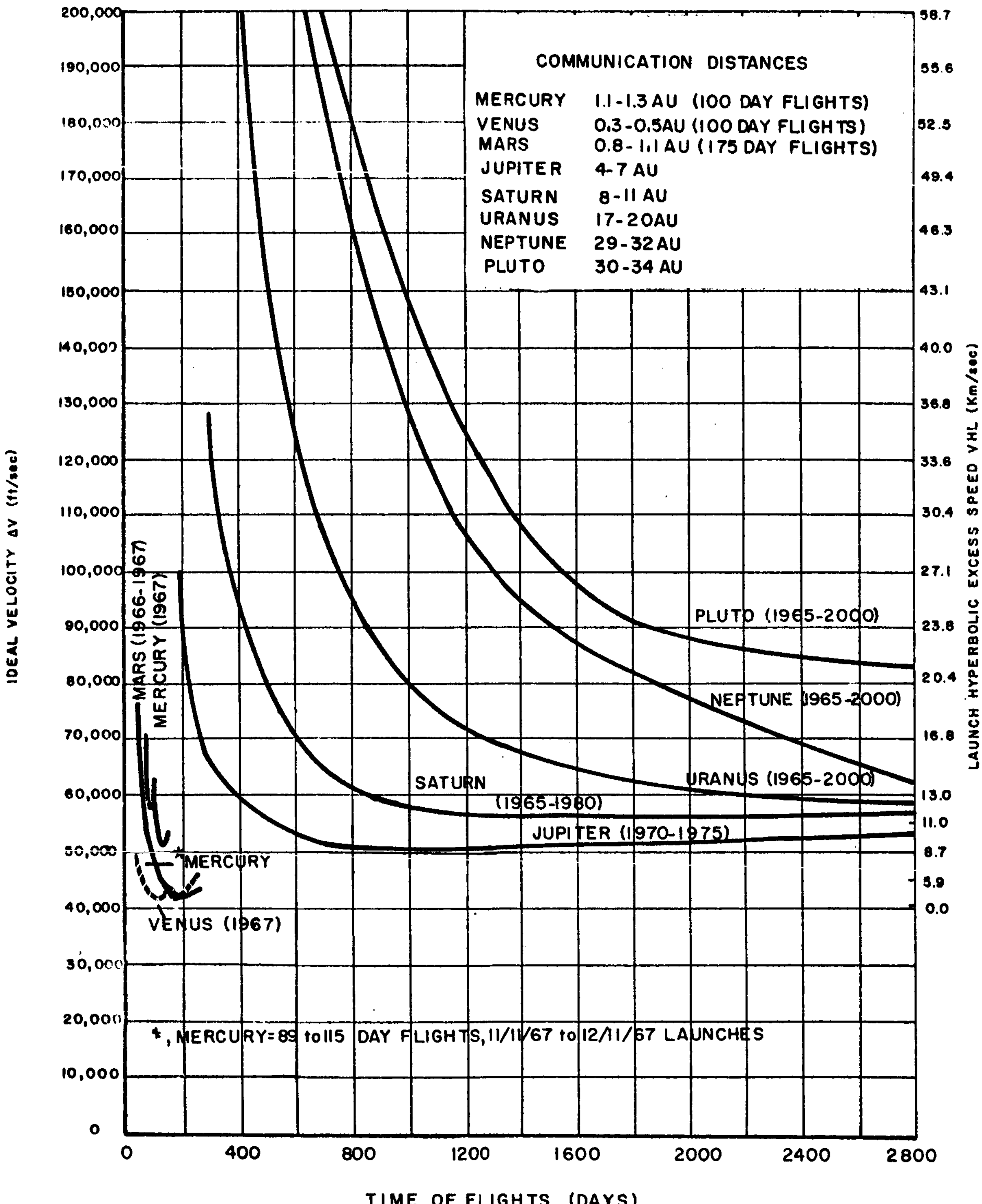


Figure 2 Ideal Velocity for Launches to the Planets Vs. Time of Flight, for 30 Day Launch Windows

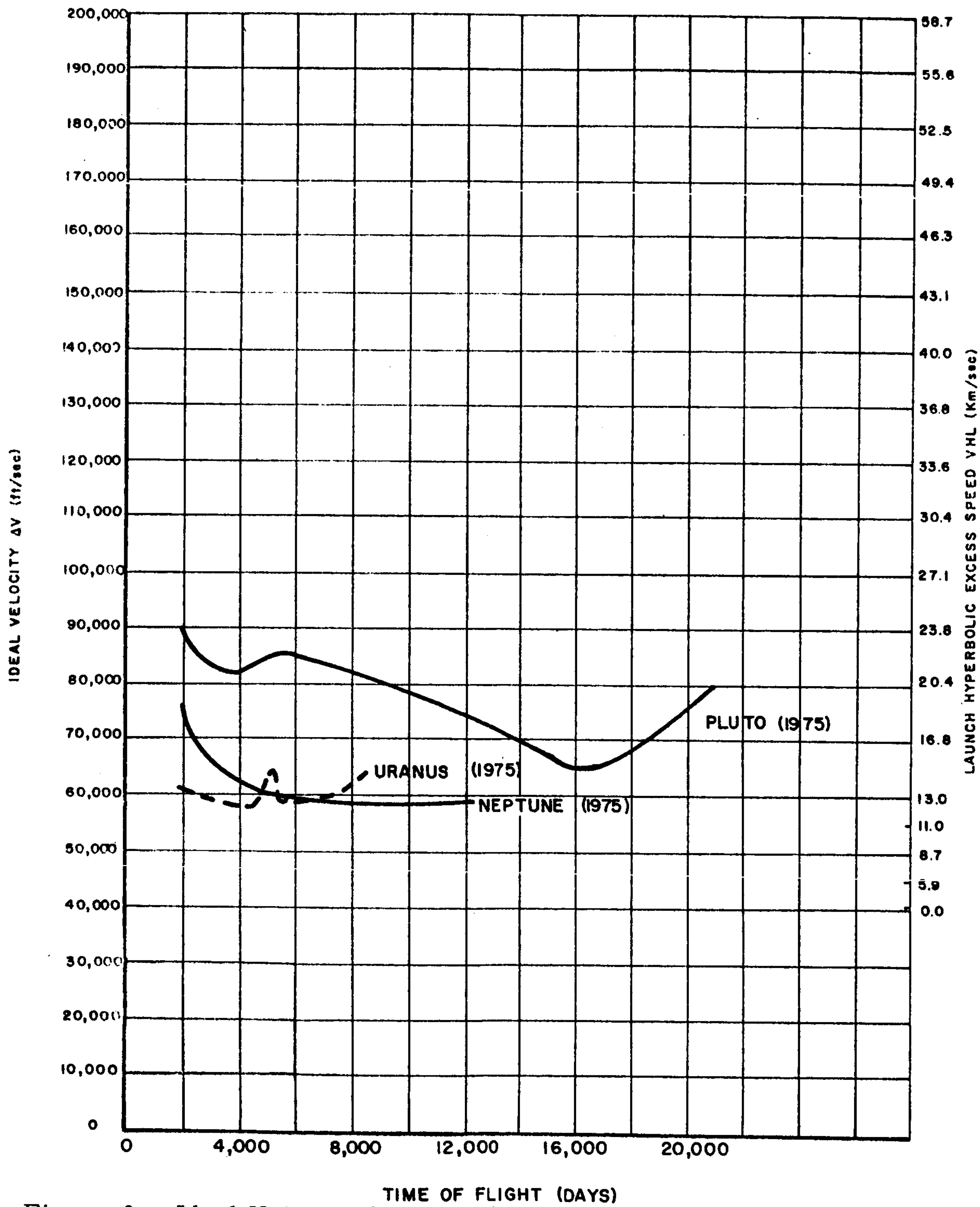


Figure 3 Ideal Velocity for Launches to the Three Outer Planets vs. Time of Flight, for 30 Day Launch Windows

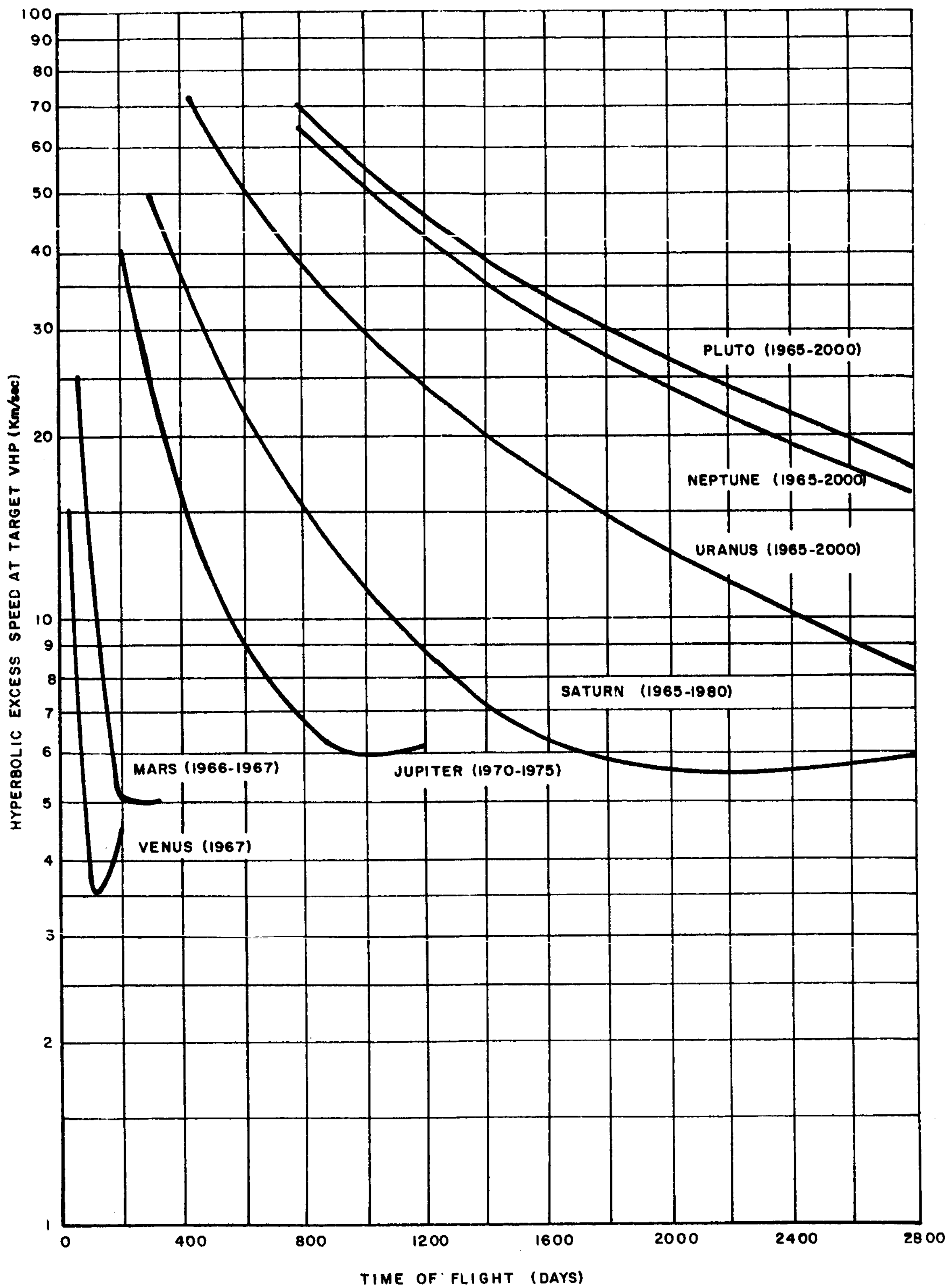


Figure 4 Hyperbolic Excess Speed at the Planets Vs. Time of Flight

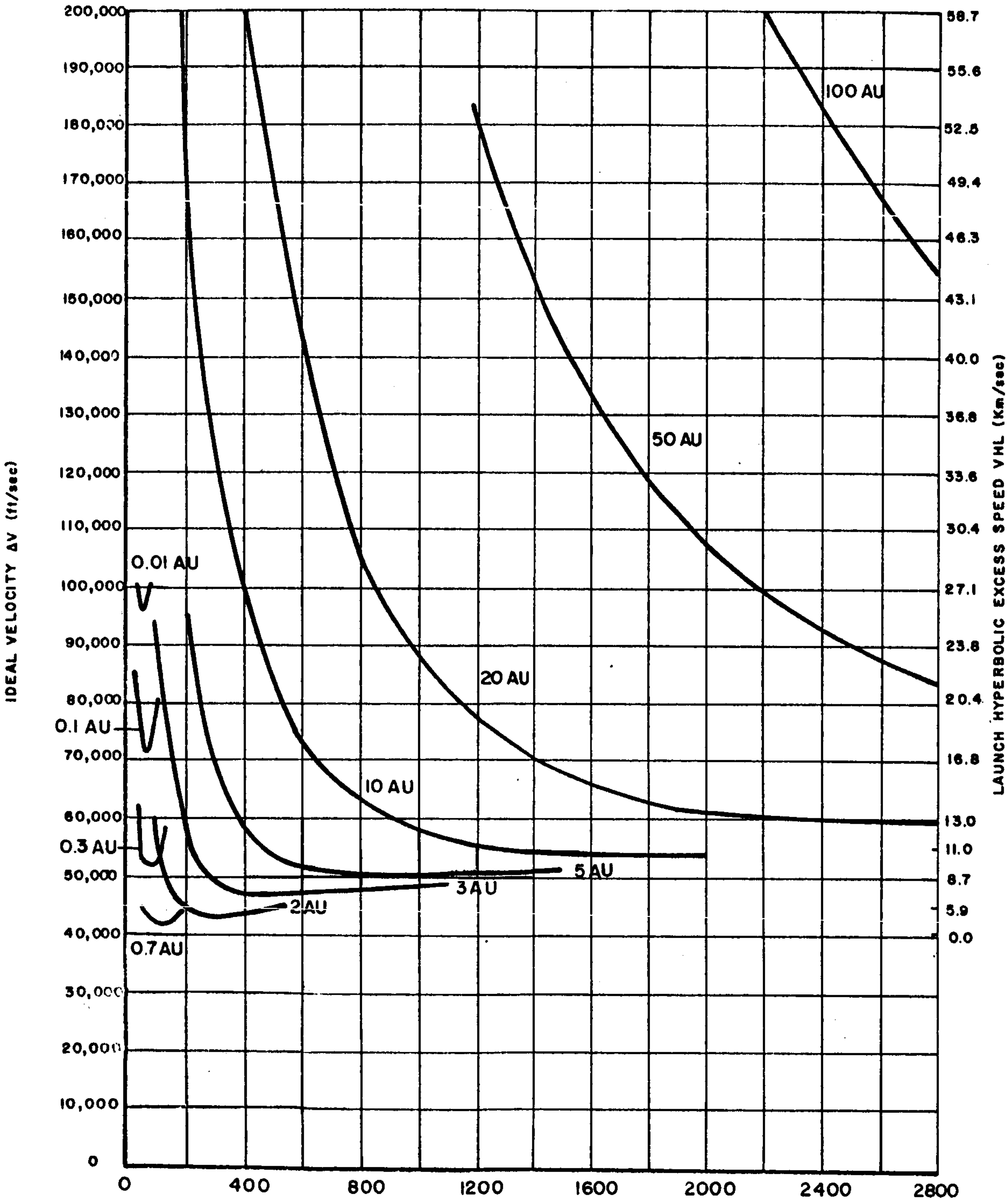


Figure 5 Ideal Velocity Vs. Time of Flight for Trajectories in the Ecliptic Plane

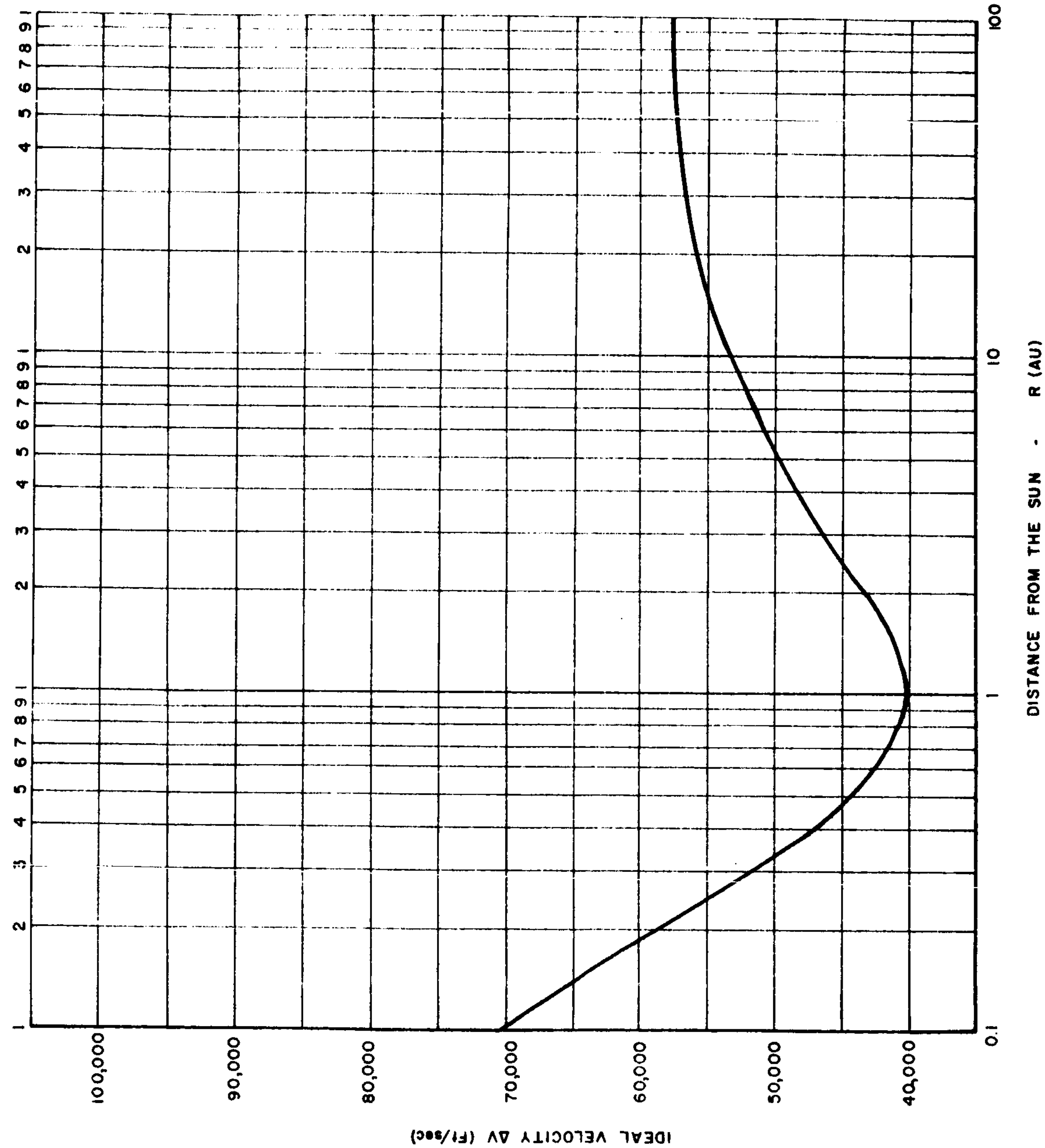


Figure 6 Ideal Velocity for Hohmann Transfers, Earth to Various Distances From the Sun

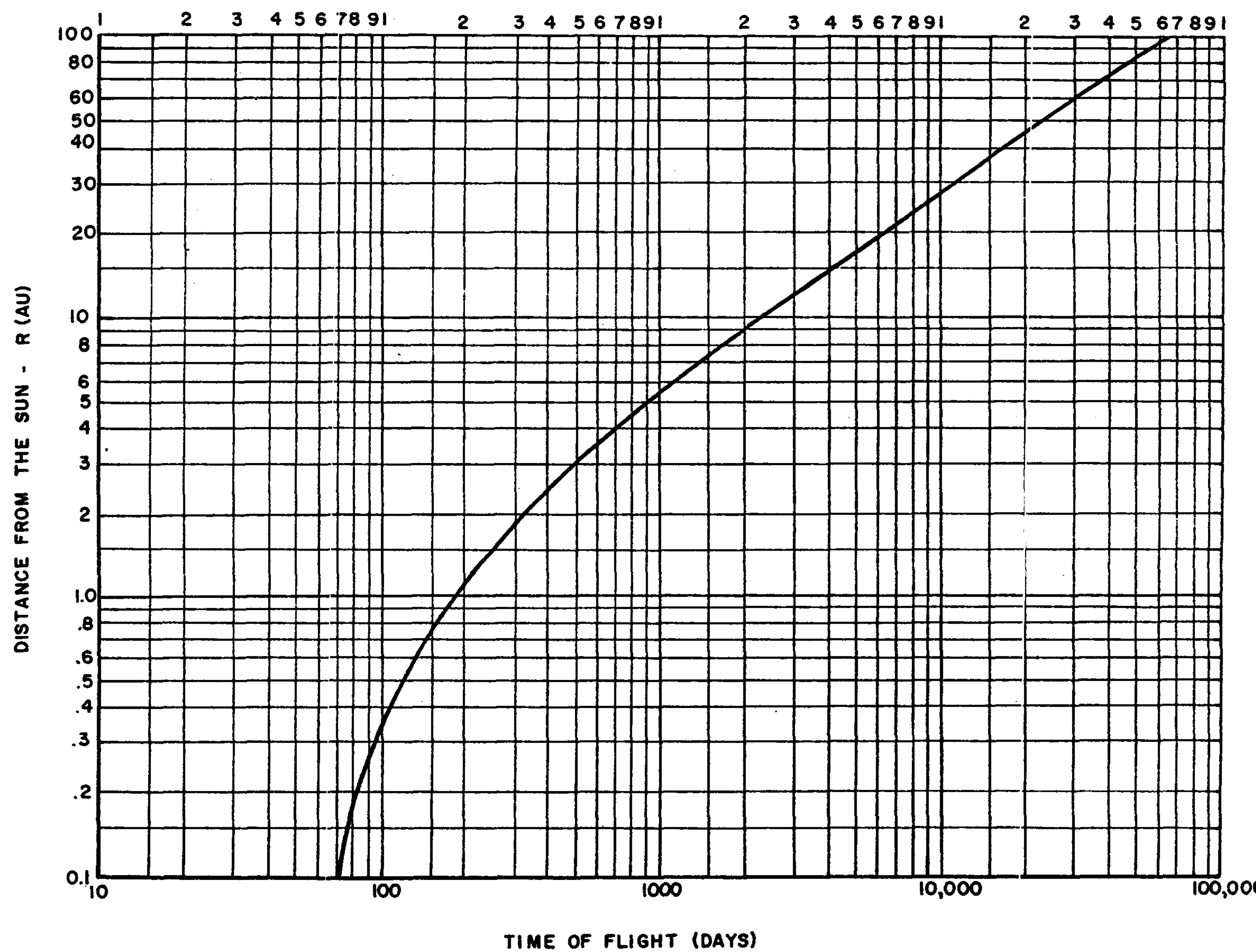


Figure 7 Time of Flight for Hohmann Transfers, Earth to Various Distances From the Sun

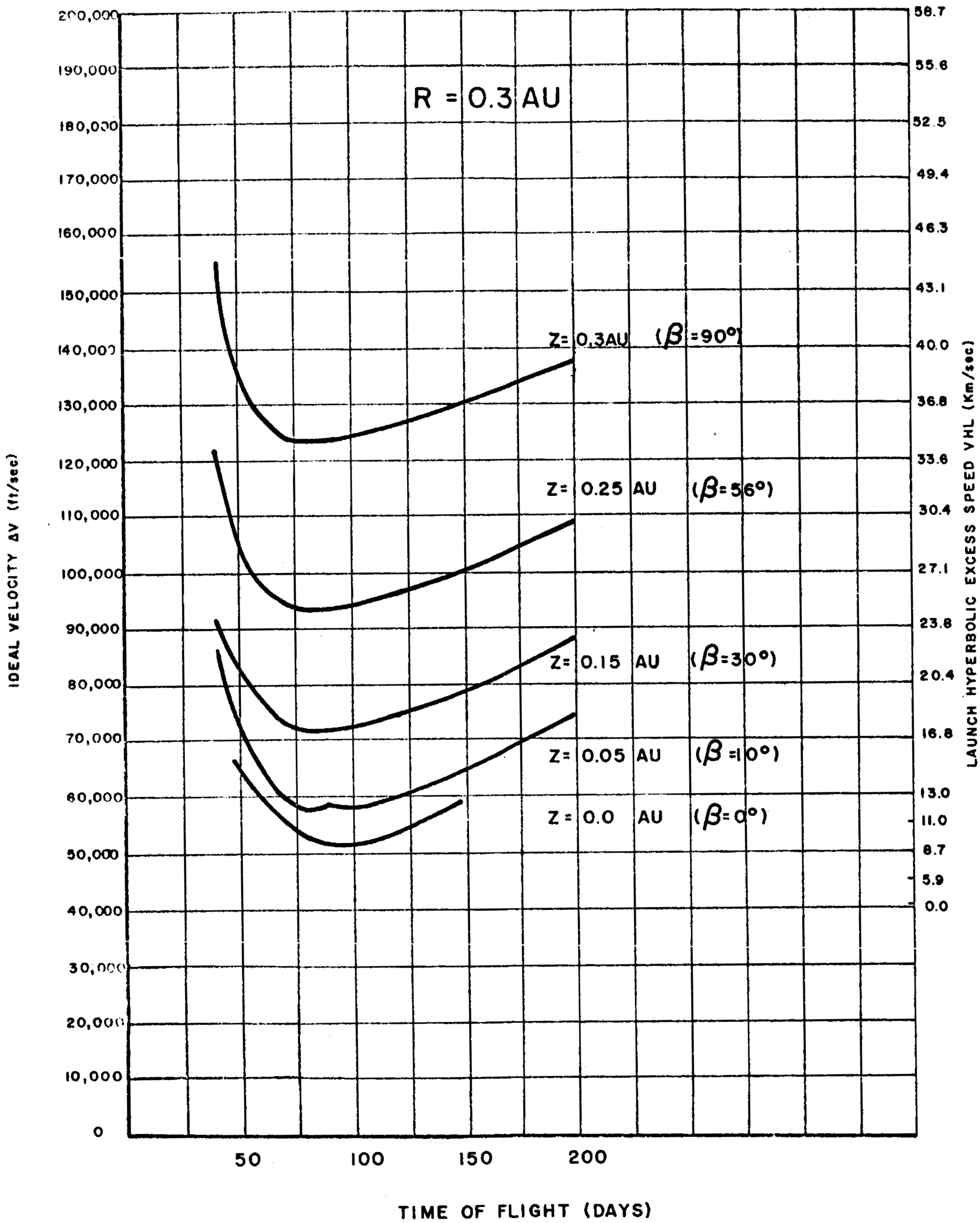


Figure 8 Ideal Velocity vs. Time of Flight for Trajectories to Distances of 0.3 AU From the Sun, For Various Distances Above the Ecliptic Plane

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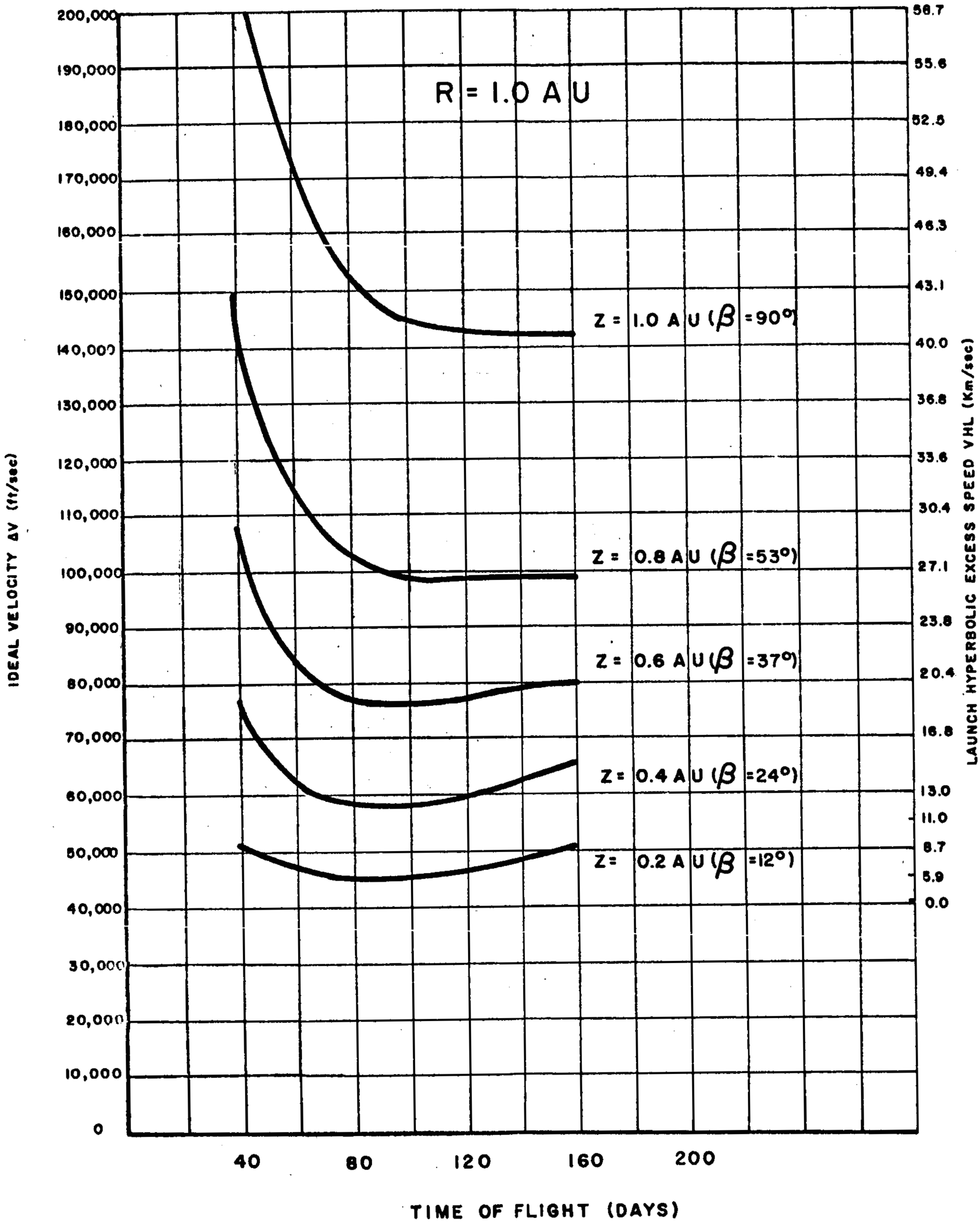


Figure 9 Ideal Velocity vs. Time of Flight for Trajectories to Distances of 1.0 AU From the Sun, For Various Distances Above the Ecliptic Plane

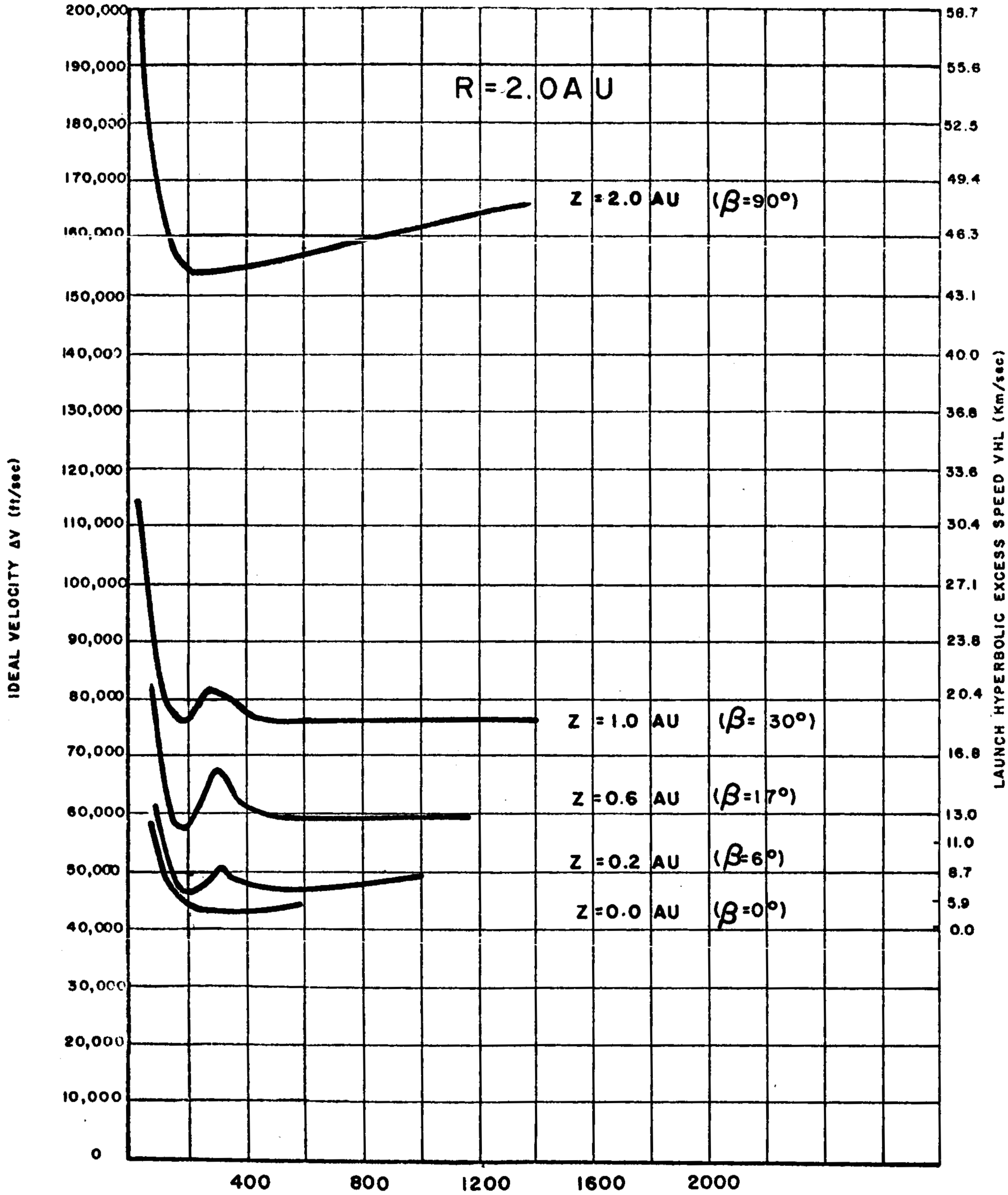


Figure 10 Ideal Velocity vs. Time of Flight for Trajectories to Distances of 2.0 AU From the Sun, For Various Distances Above the Ecliptic Plane

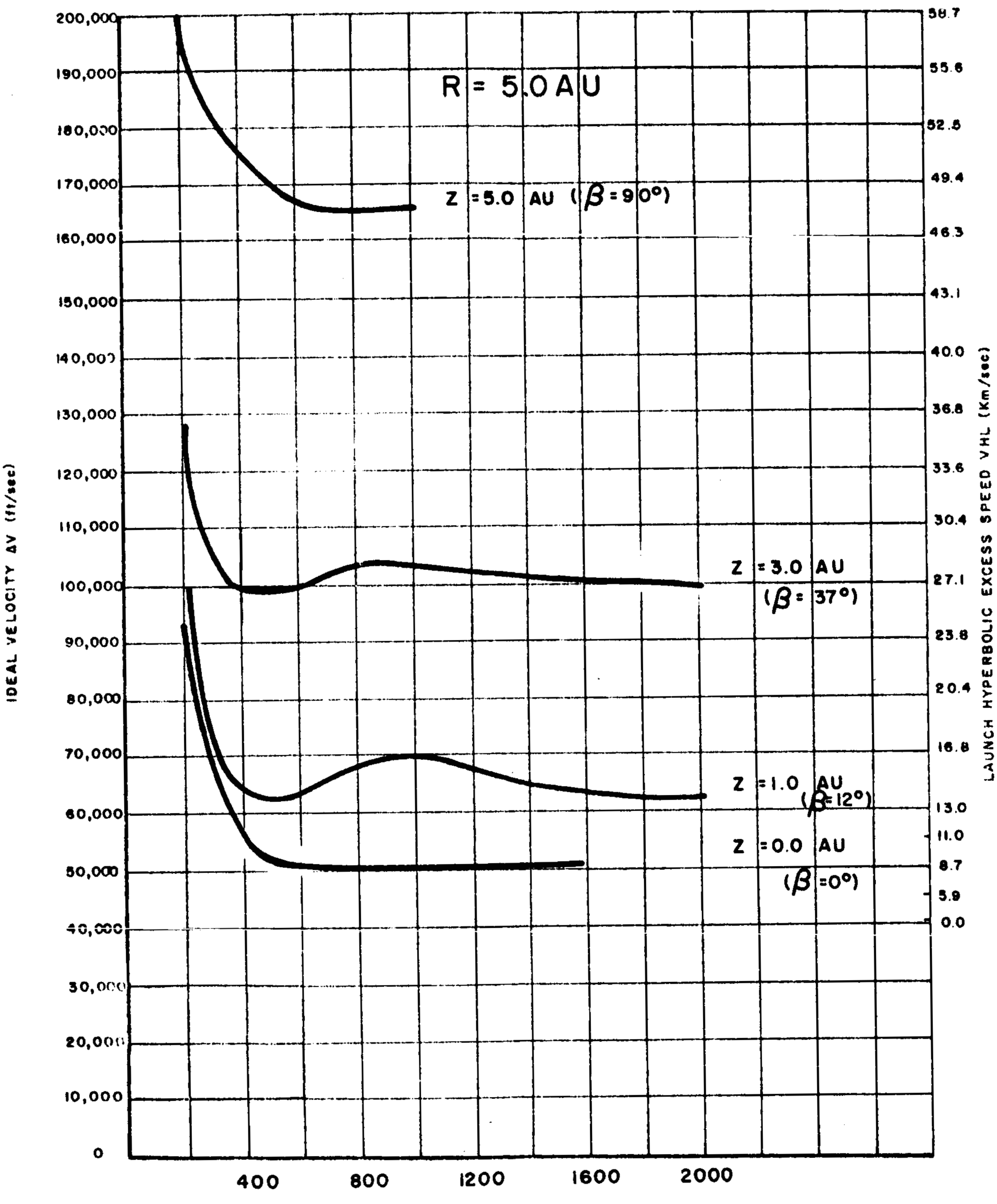


Figure 11 Ideal Velocity vs. Time of Flight for Trajectories to Distances of 5.0 AU From the Sun, For Various Distances Above the Ecliptic Plane

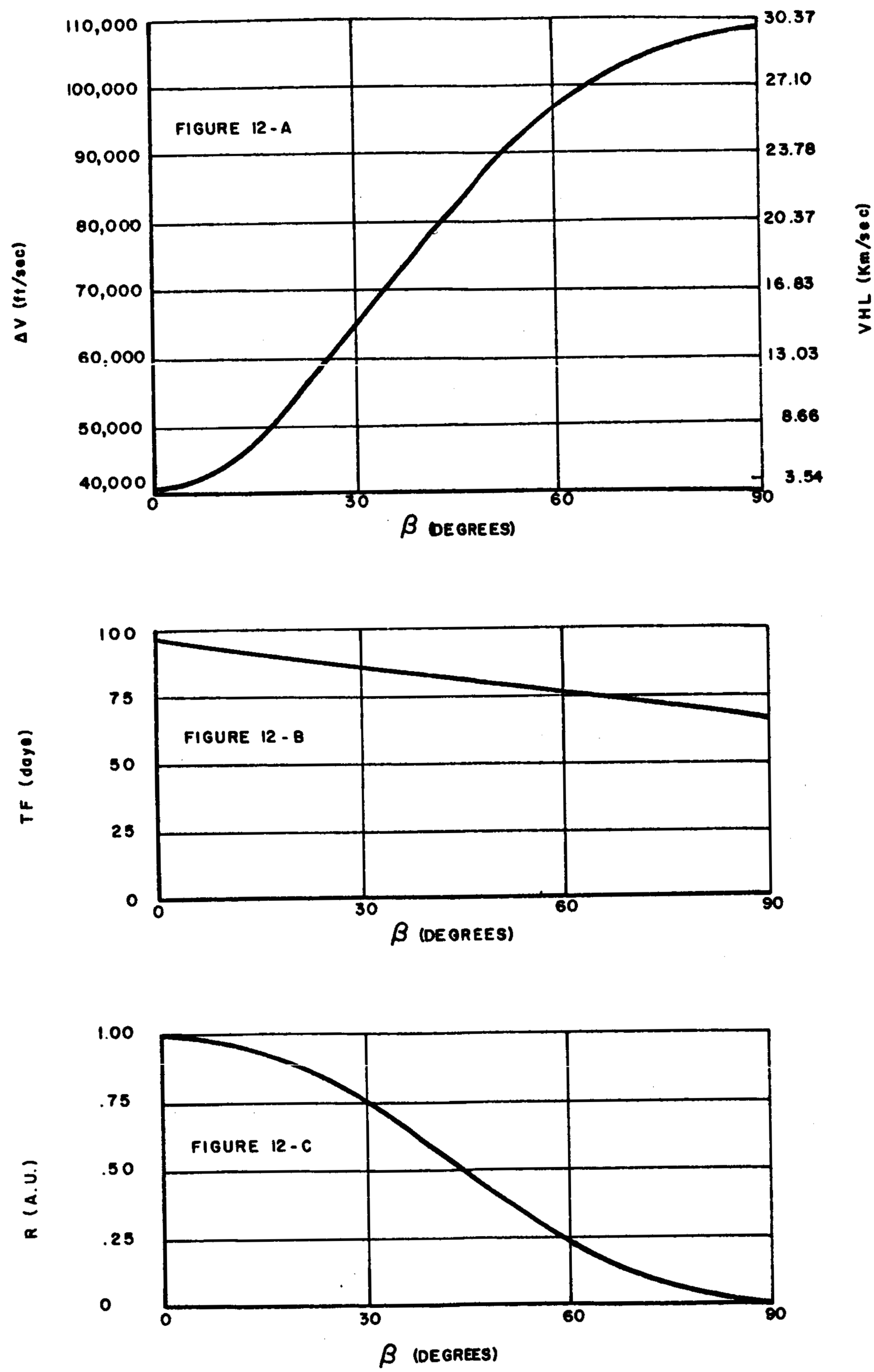


Figure 12 Ideal Velocity, Time of Flight and Heliocentric Radial Distances For Minimum Energy Flights to All Angles Out of the Ecliptic Plane

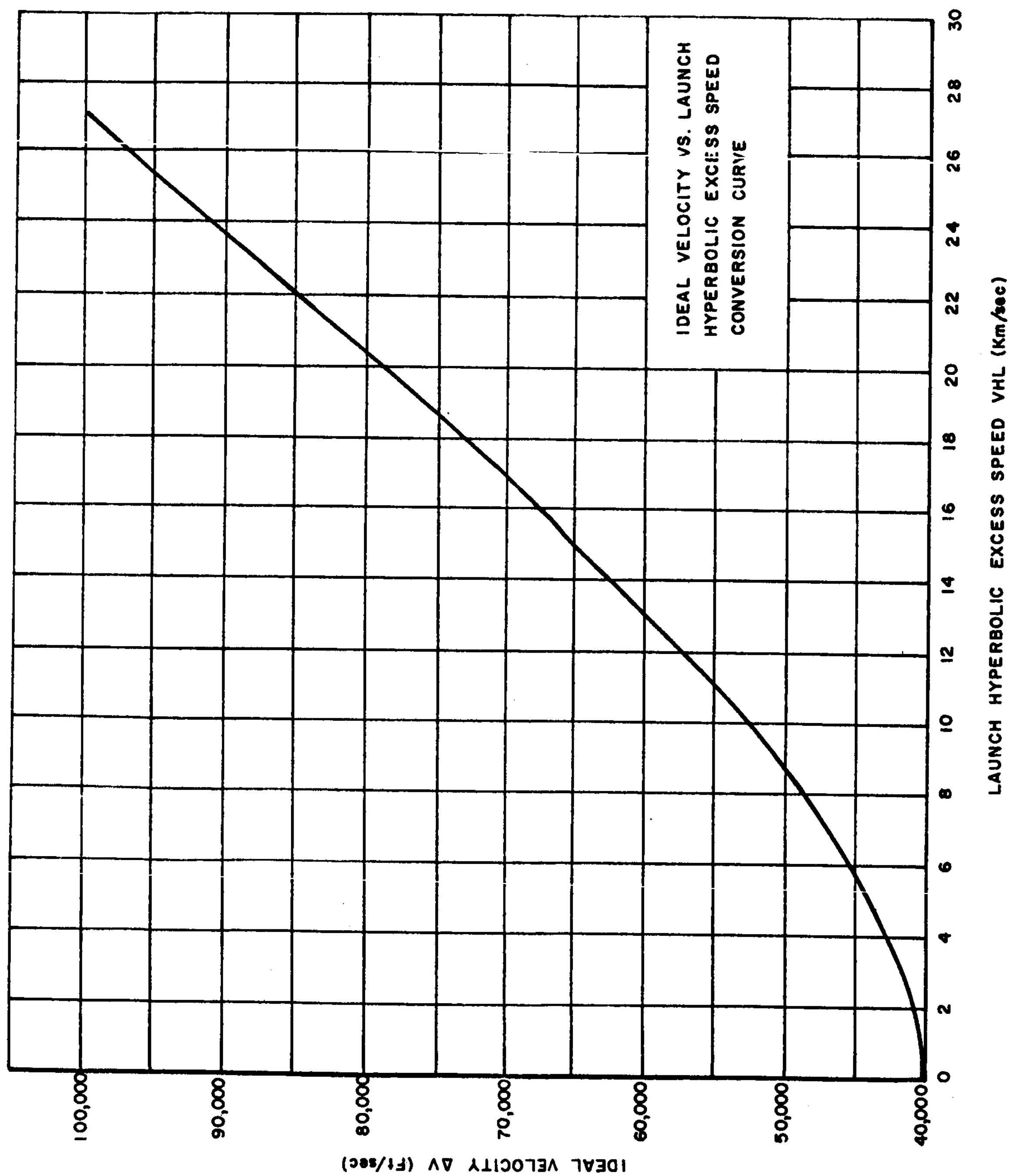


Figure 13 Ideal Velocity vs. Launch Hyperbolic Excess Speed: Conversion Curve

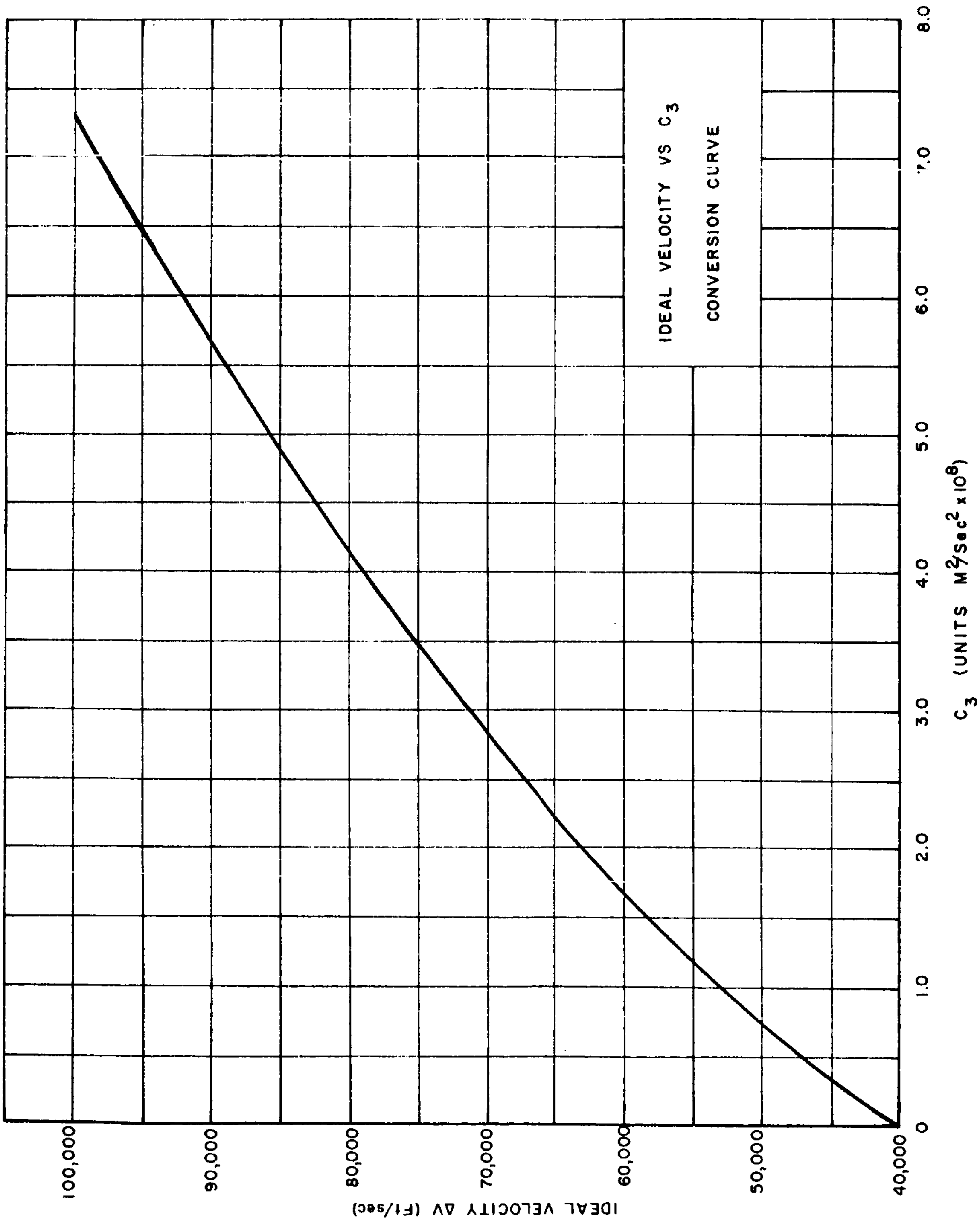


Figure 14 Ideal Velocity vs. $C_3$ : Conversion Curve

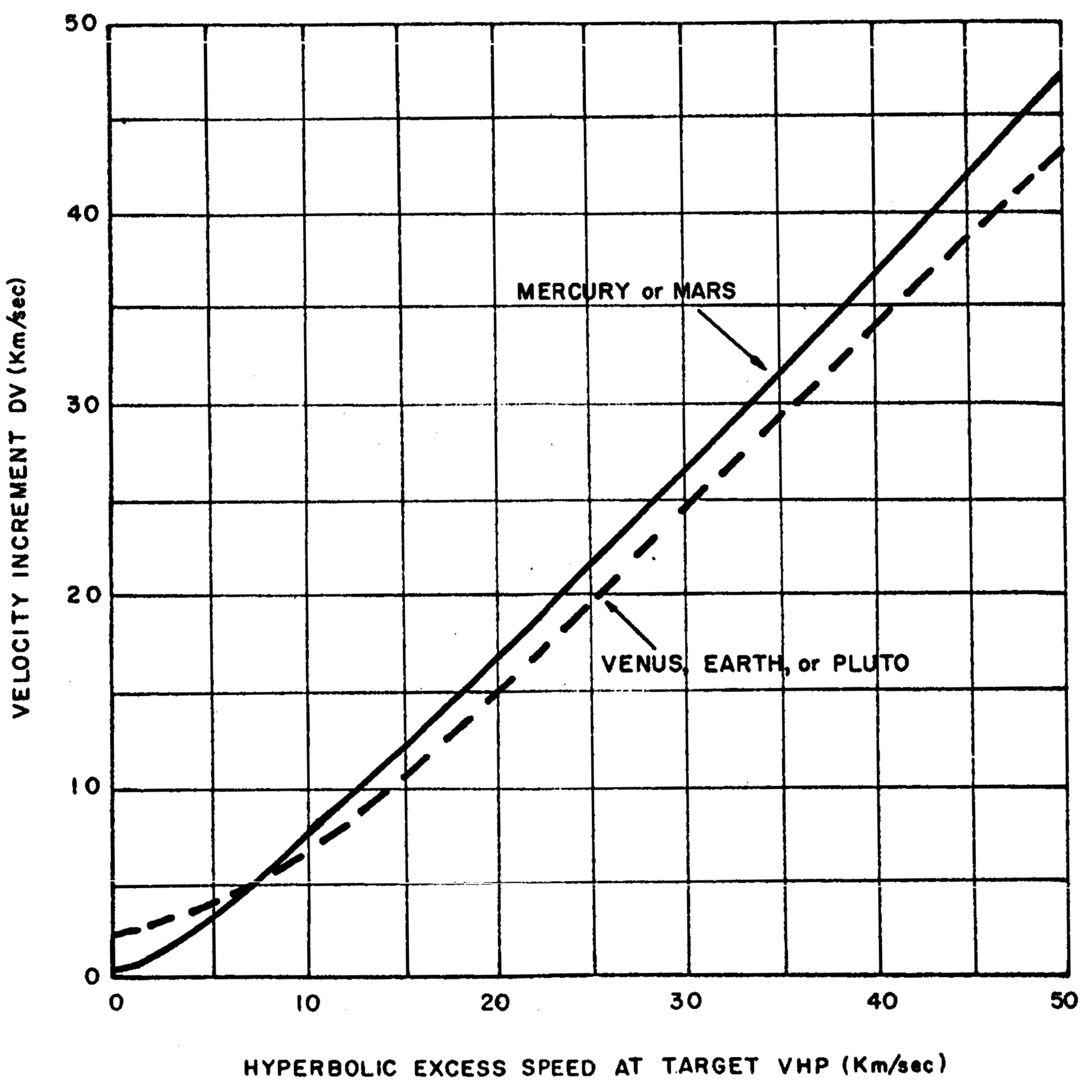


Figure 15 Velocity Increment to Transfer from Approach Hyperbolas to Orbits Around the Planets, vs. Hyperbolic Speed of Approach, Valid for All Orbits with Perigee Above the Planet Atmosphere and Apogee $\ll$ One Planet Radius Above the Surface

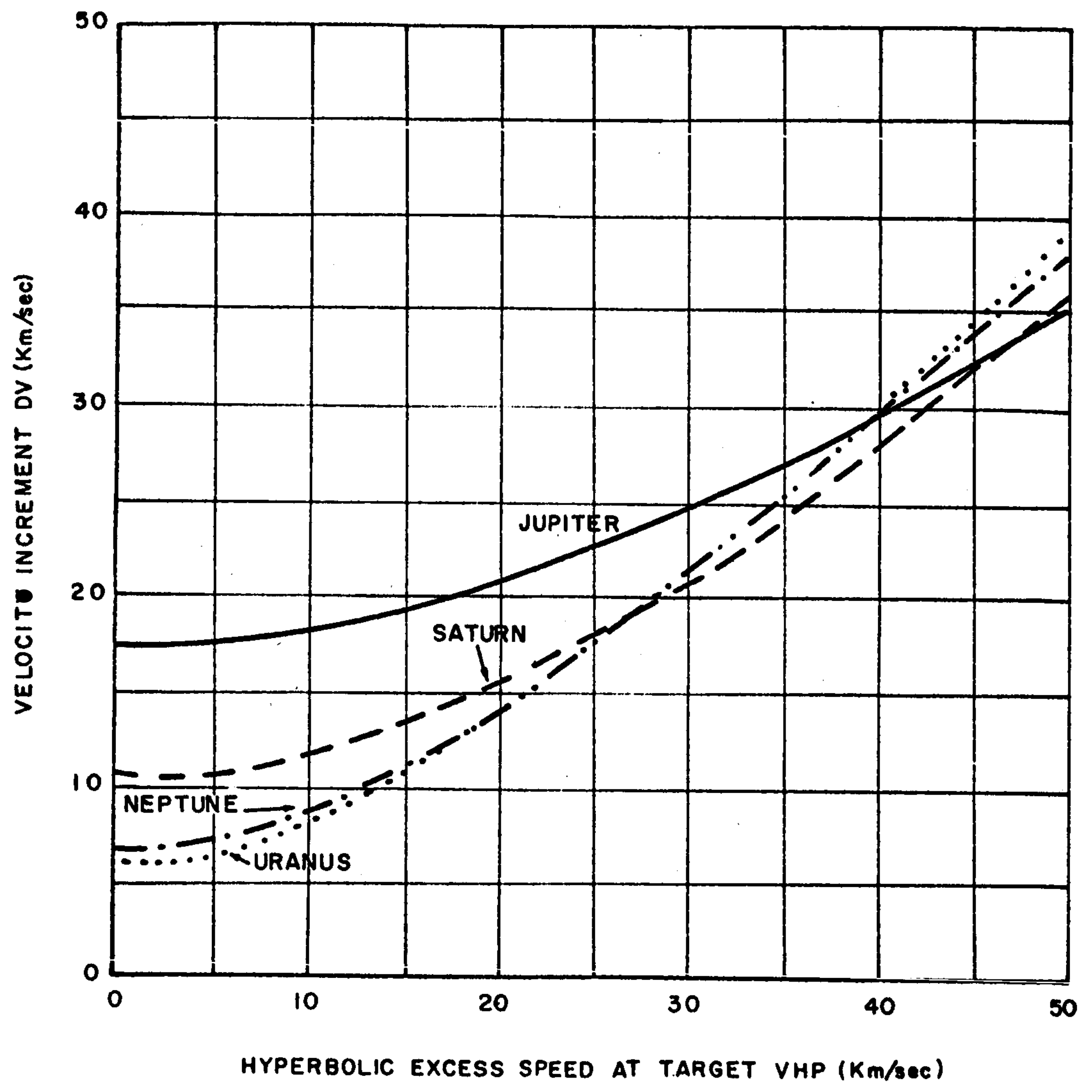


Figure 16 Velocity Increment to Transfer from Approach Hyperbolas to Orbits Around the Planets, vs. Hyperbolic Speed of Approach, Valid for All Orbits with Perigee Above the Planet Atmosphere and Apogee ≪ One Planet Radius Above the Surface

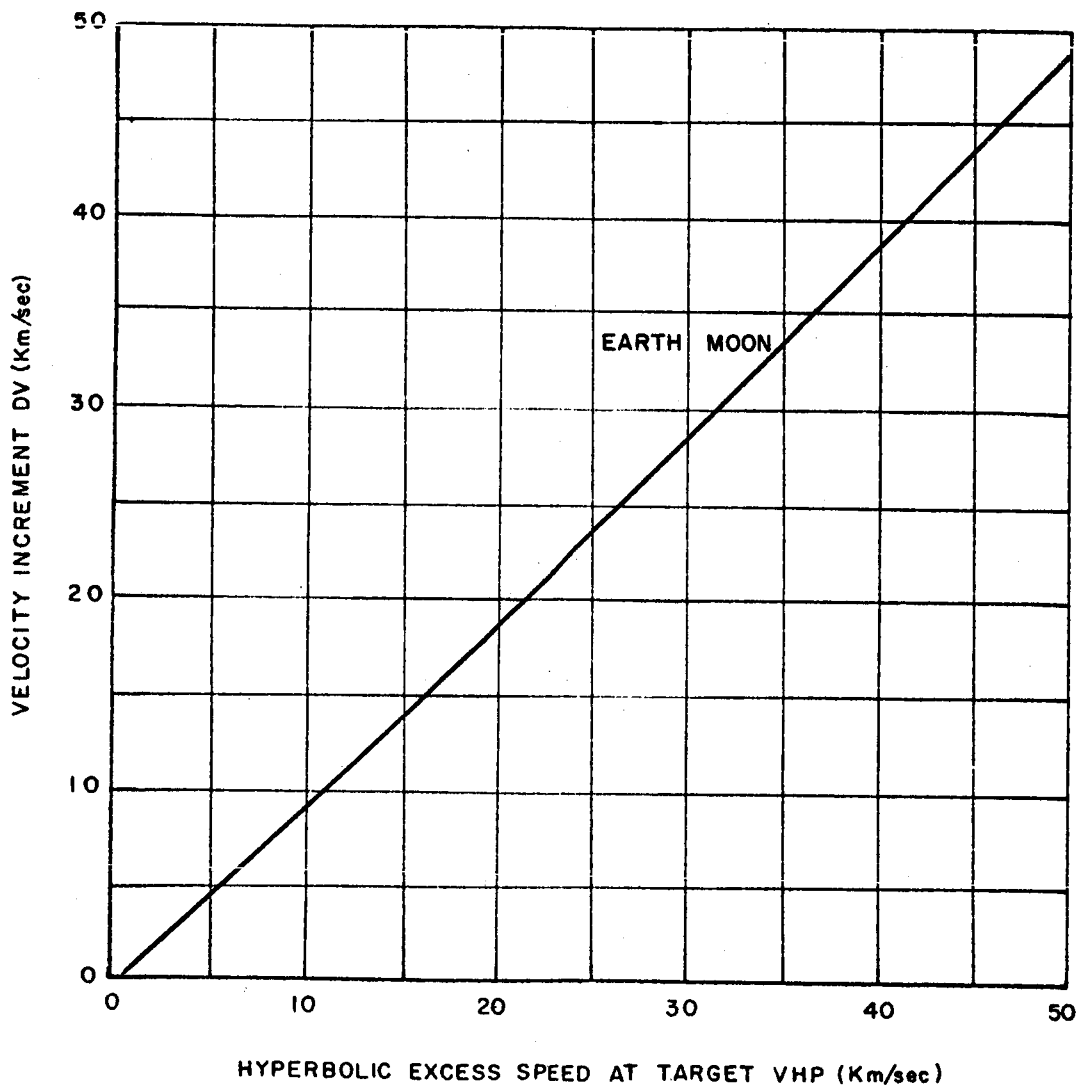


Figure 17 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Earth Satellite the Moon

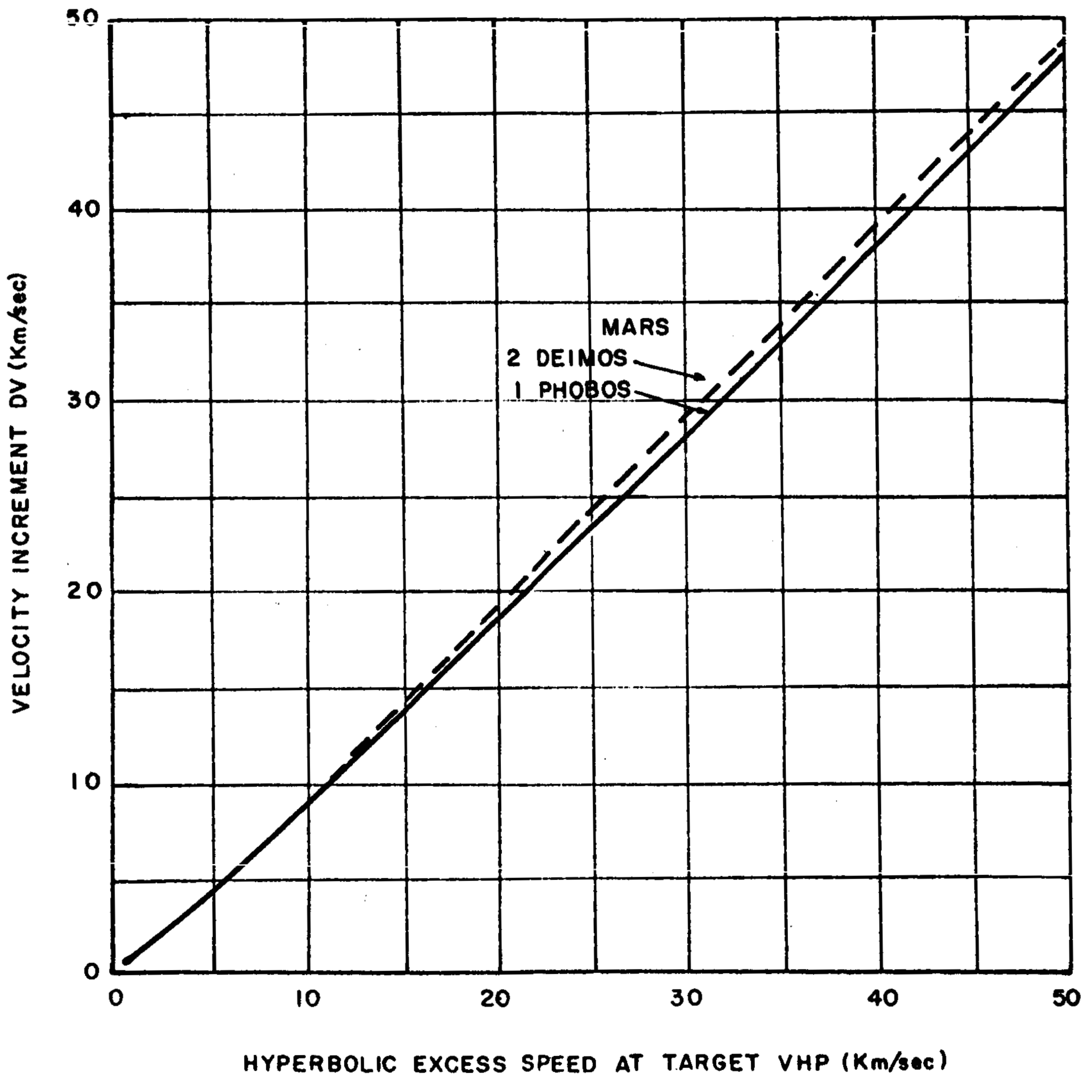


Figure 18 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Mars Satellites Phobos and Deimos

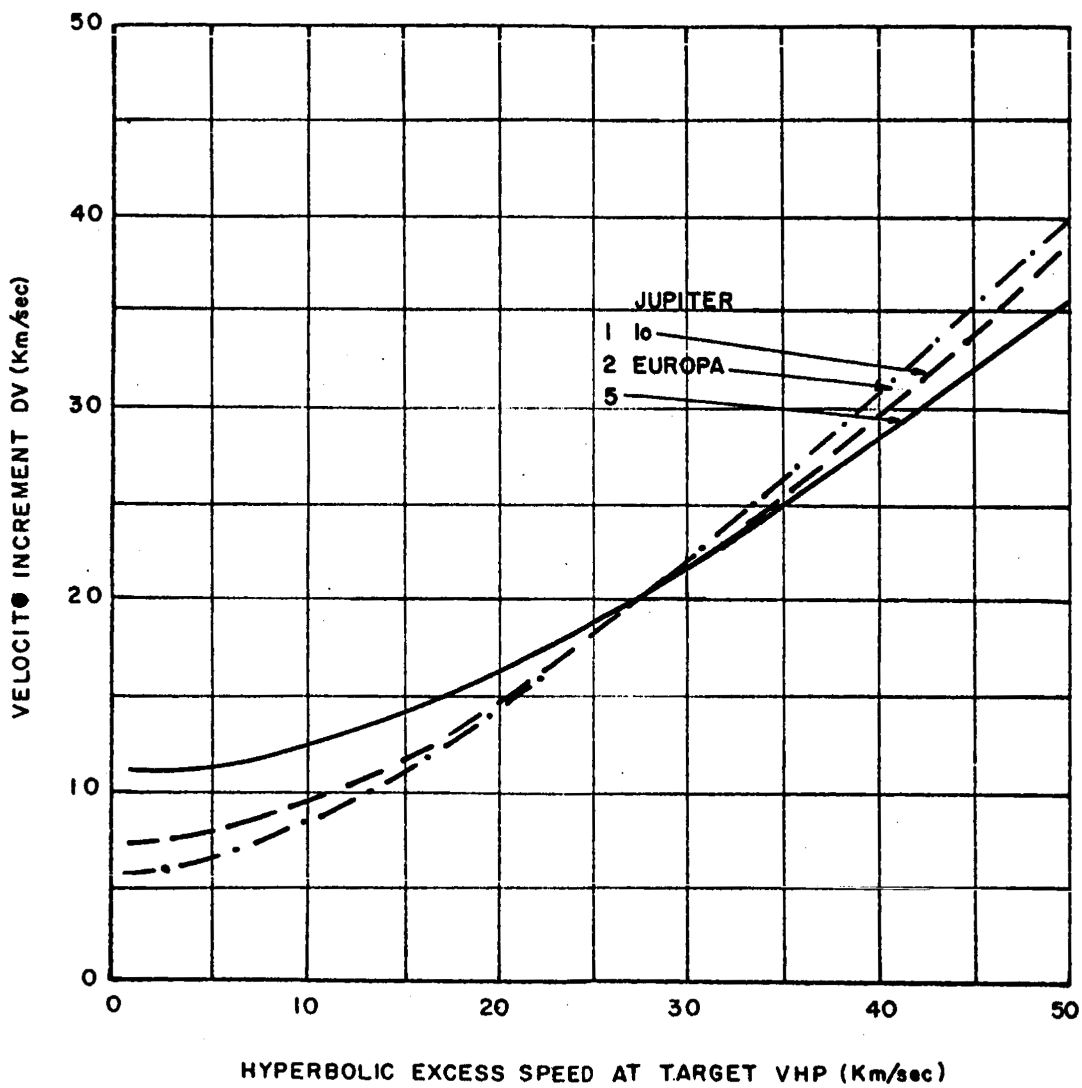


Figure 19 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Jupiter Satellites 1 (Io), 2 (Europa) and 5

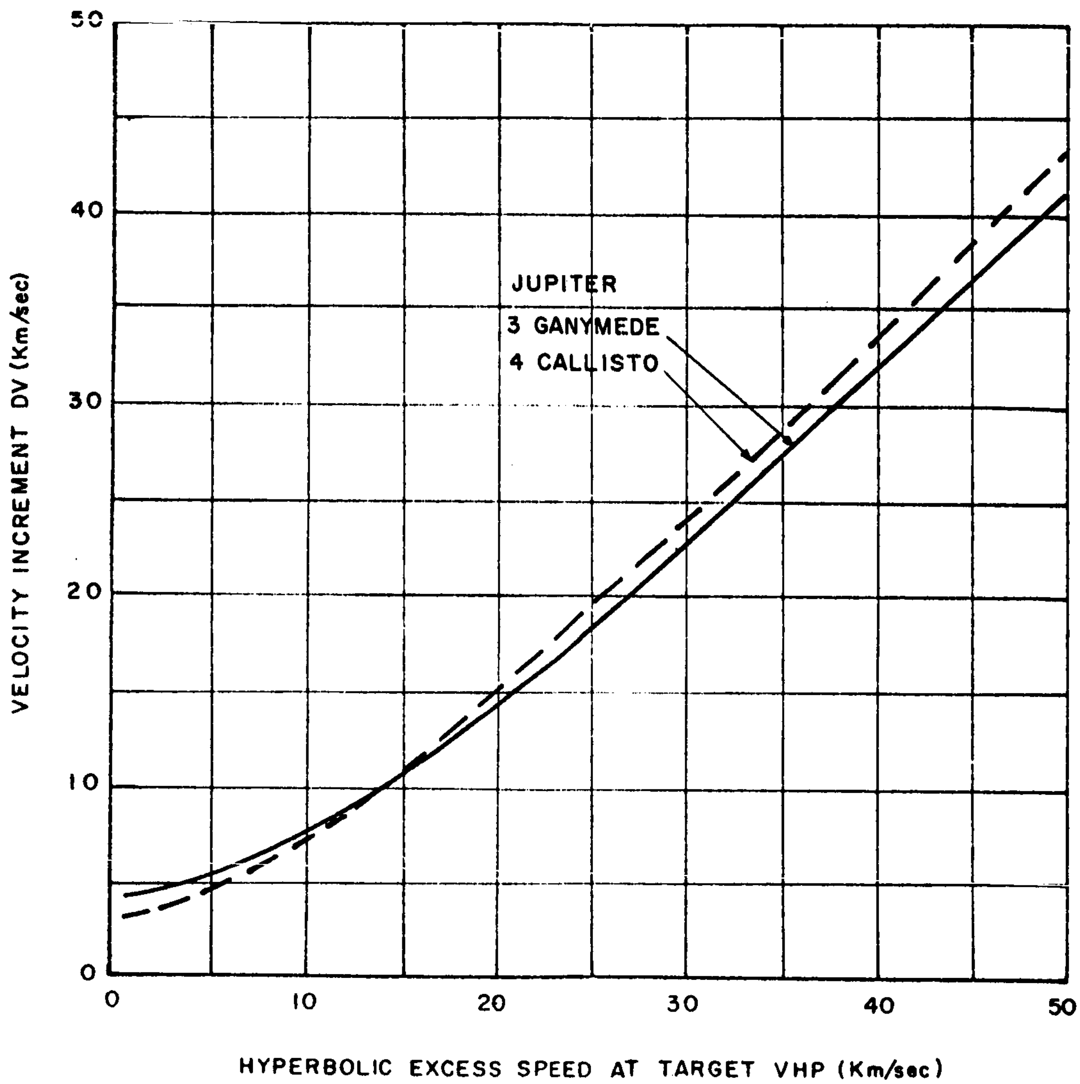


Figure 20 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Jupiter Satellites 3 (Ganymede) and 4 (Callisto)

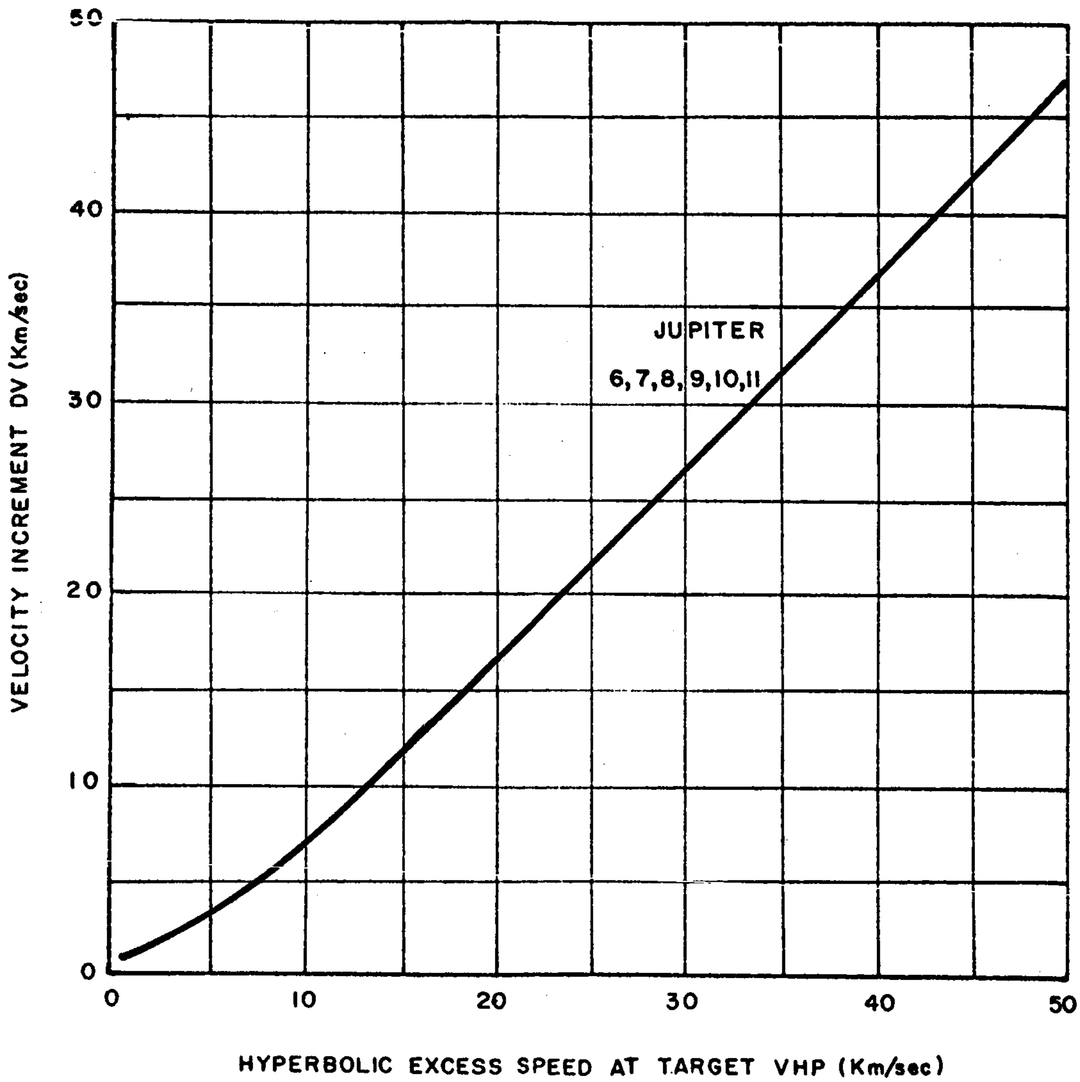


Figure 21 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Jupiter Satellites 6 through 11

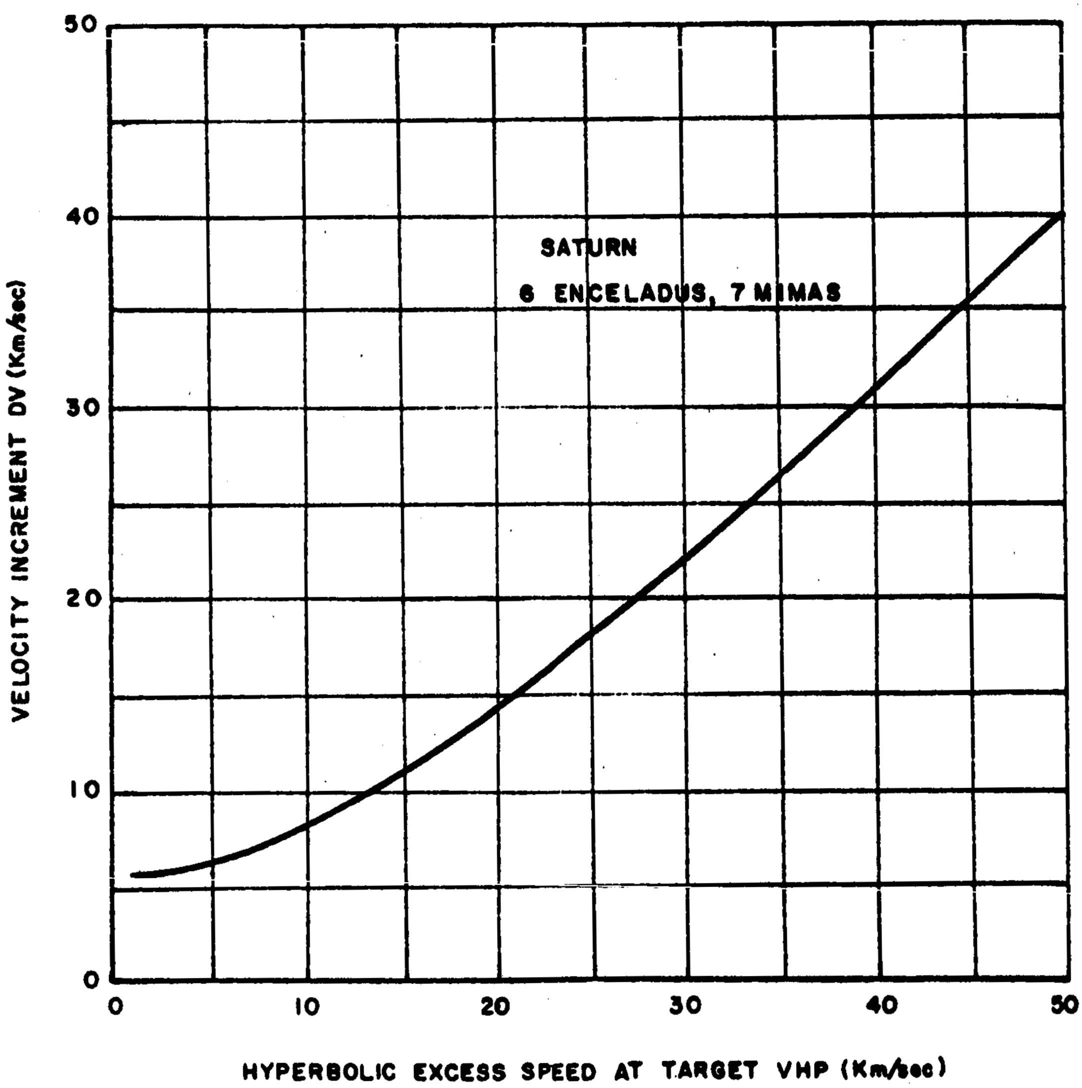


Figure 22 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Saturn Satellites 6 (Enceladus) and 7 (Mimas)

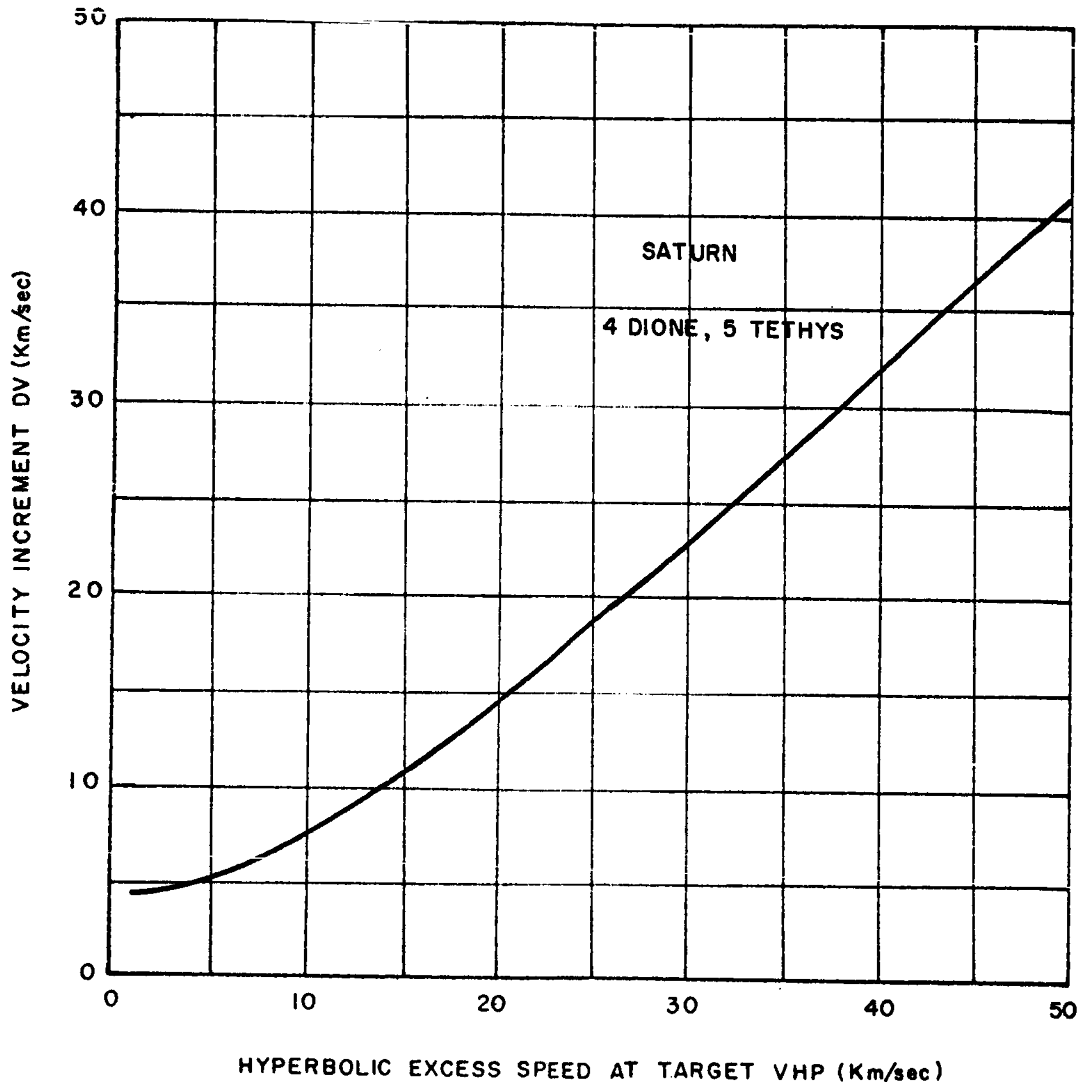


Figure 23 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching That of the Satellites: For Saturn Satellites 4 (Dione) and 5 (Tethys)

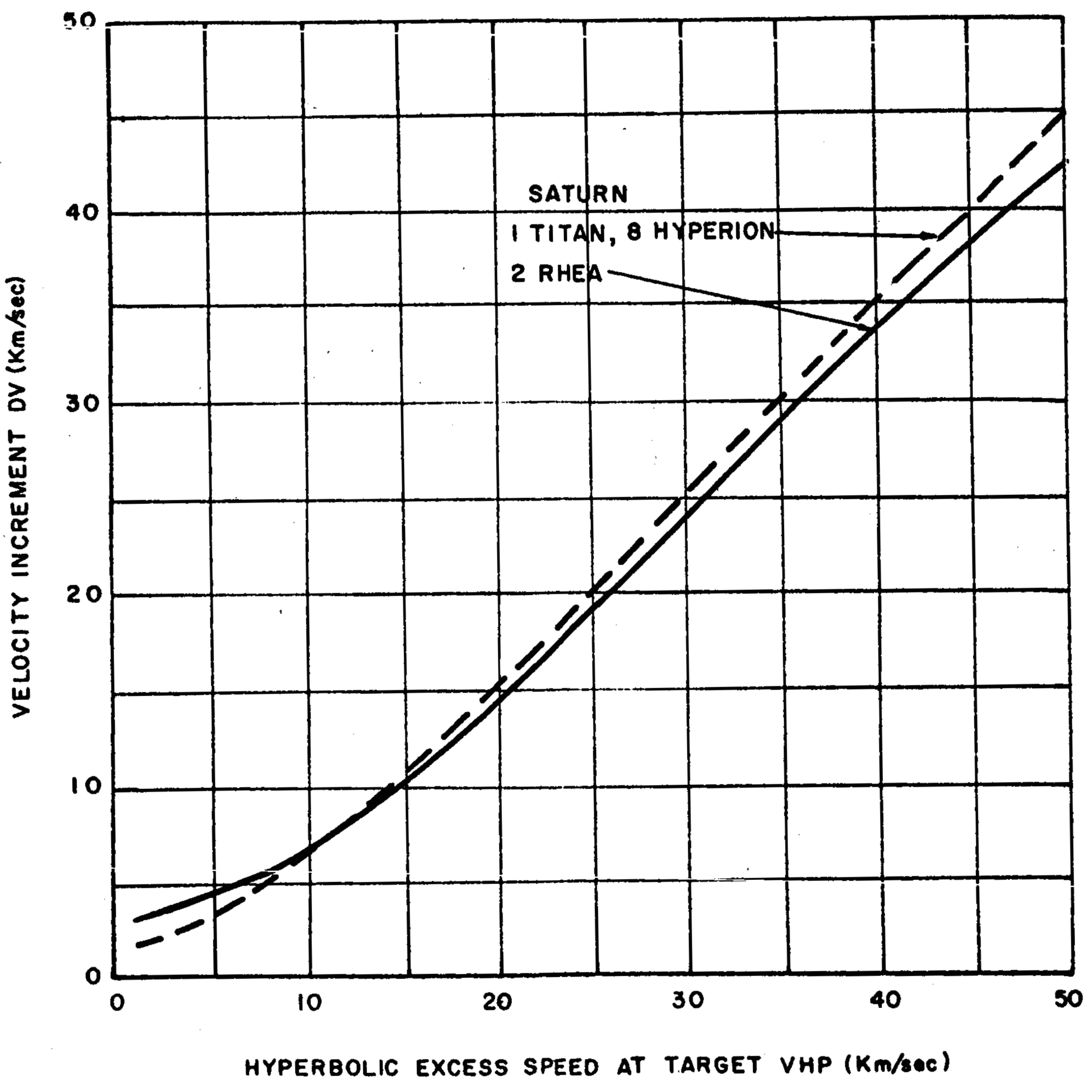


Figure 24 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching That of the Satellites: For Saturn Satellites 1 (Titan), 8 (Hyperion) and 2 (Rhea)

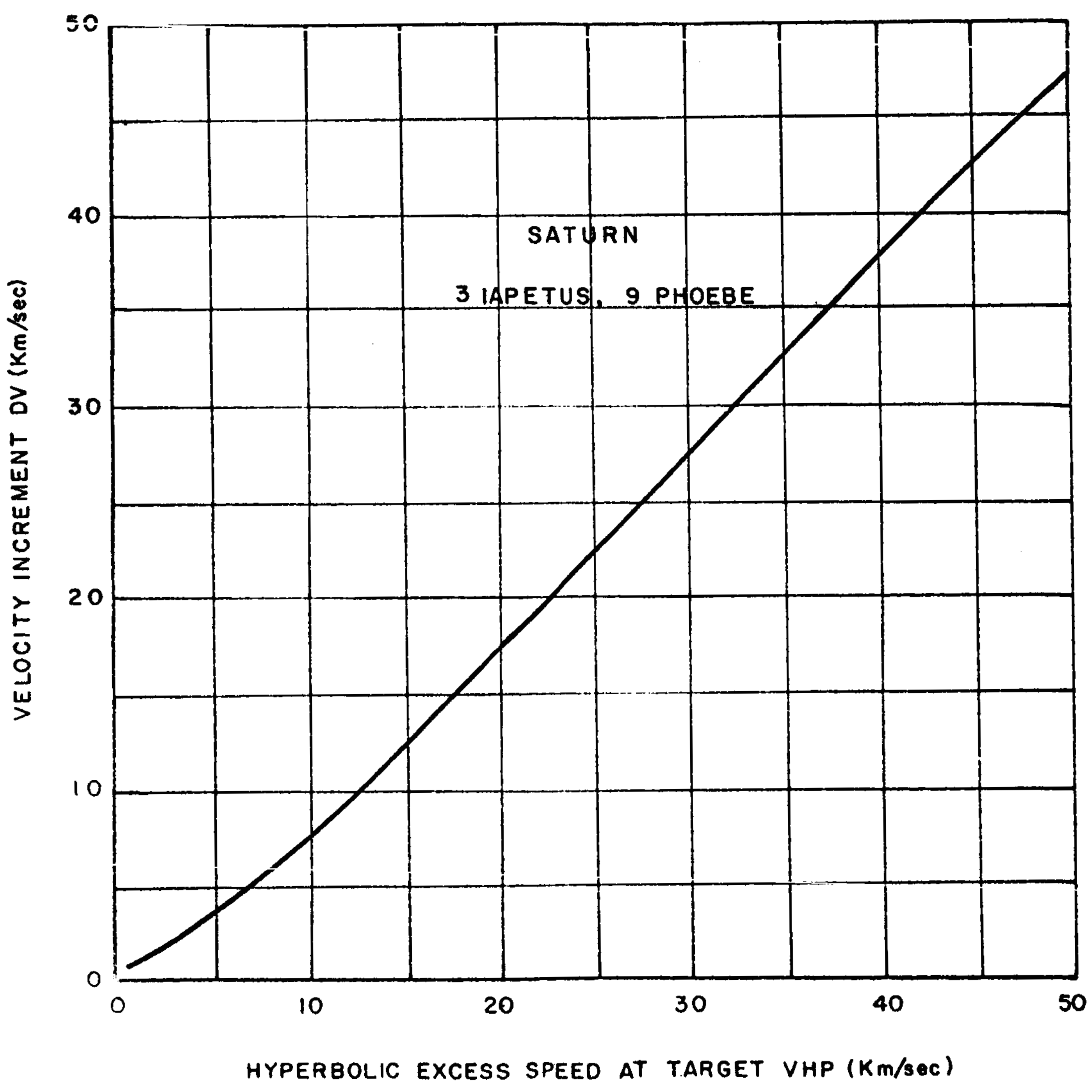


Figure 25 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Saturn Satellites 3 (Iapetus) and 9 (Phoebe)

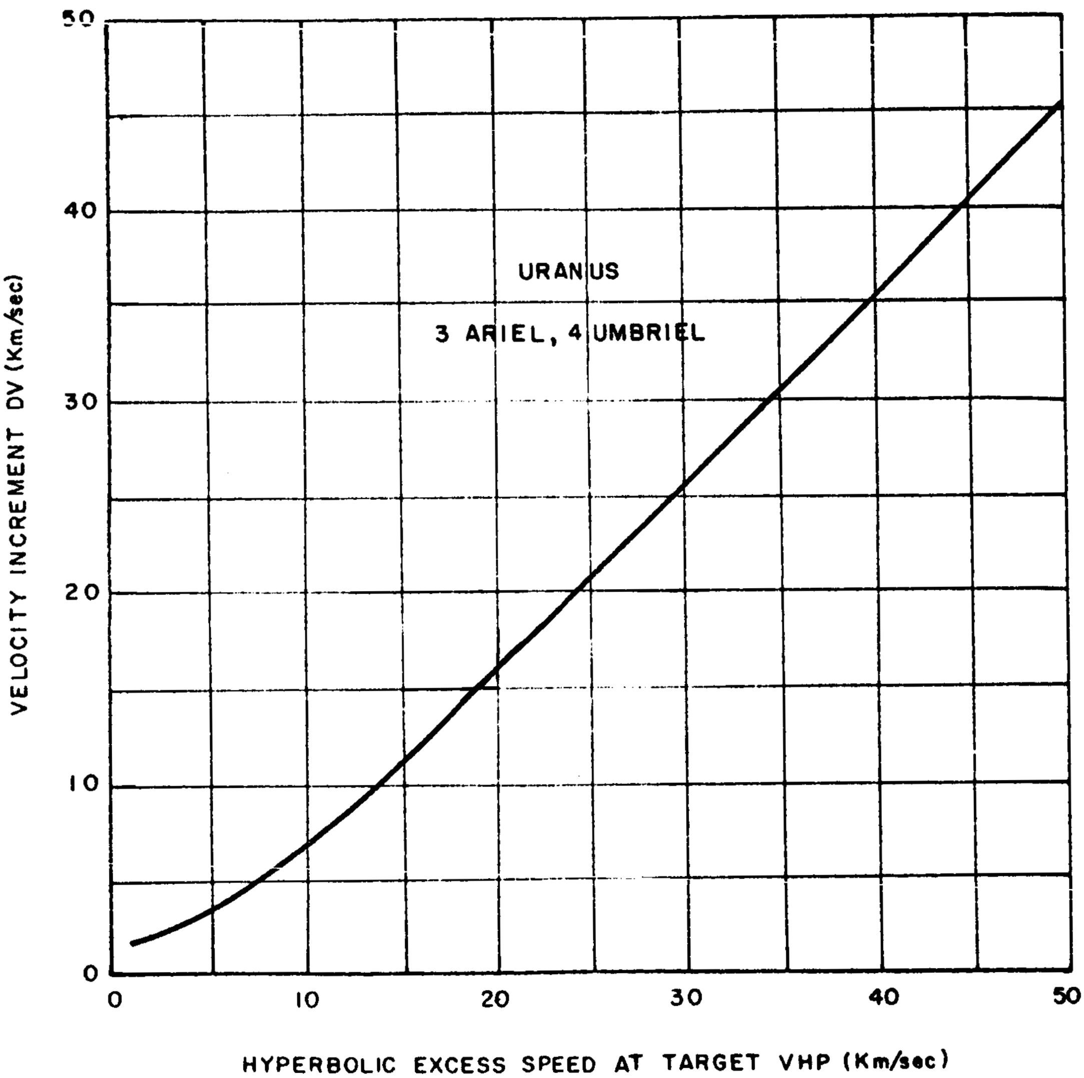


Figure 26 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Uranus Satellites 3 (Ariel) and 4 (Umbriel)

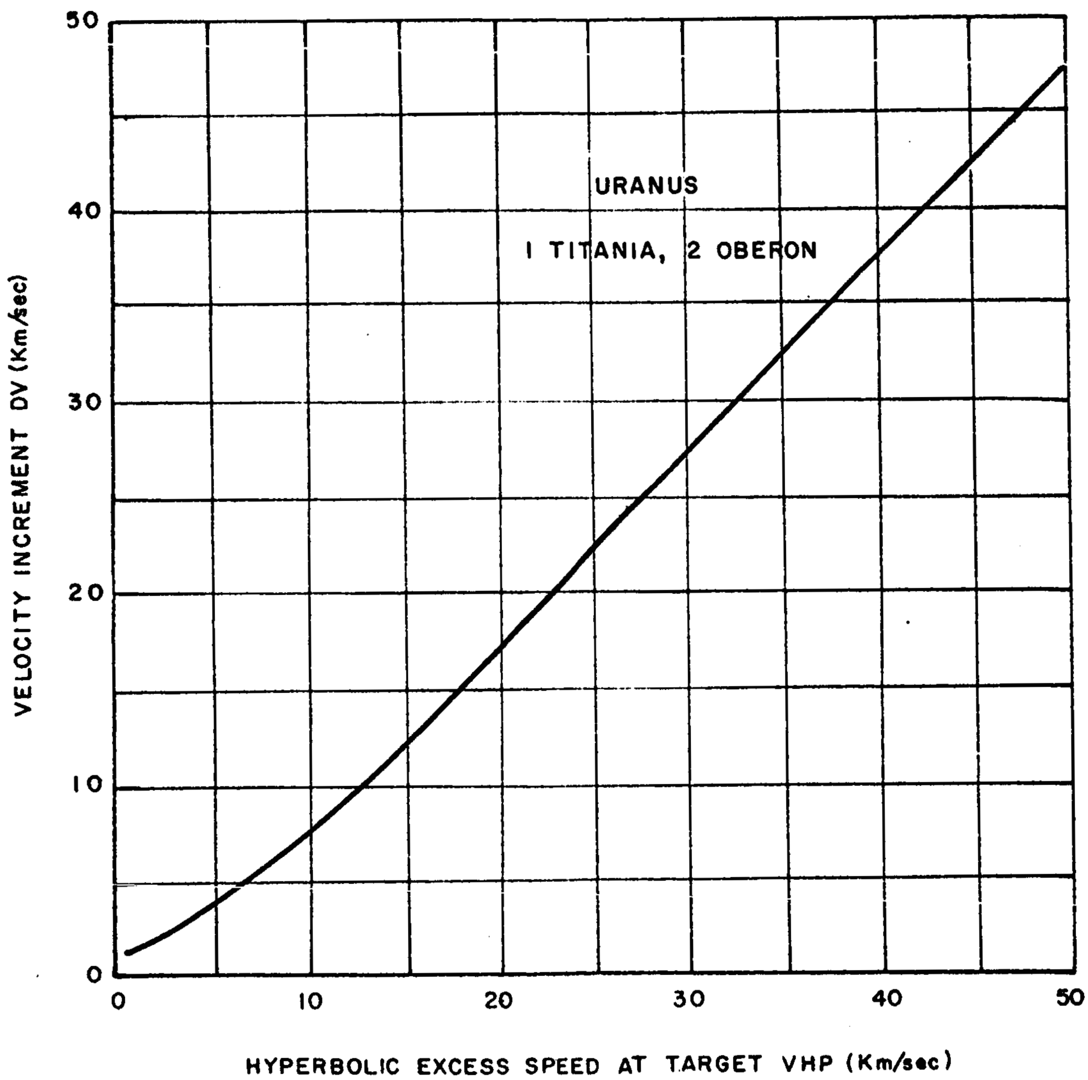


Figure 27 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Uranus Satellites 1 (Titania) and 2 (Oberon)

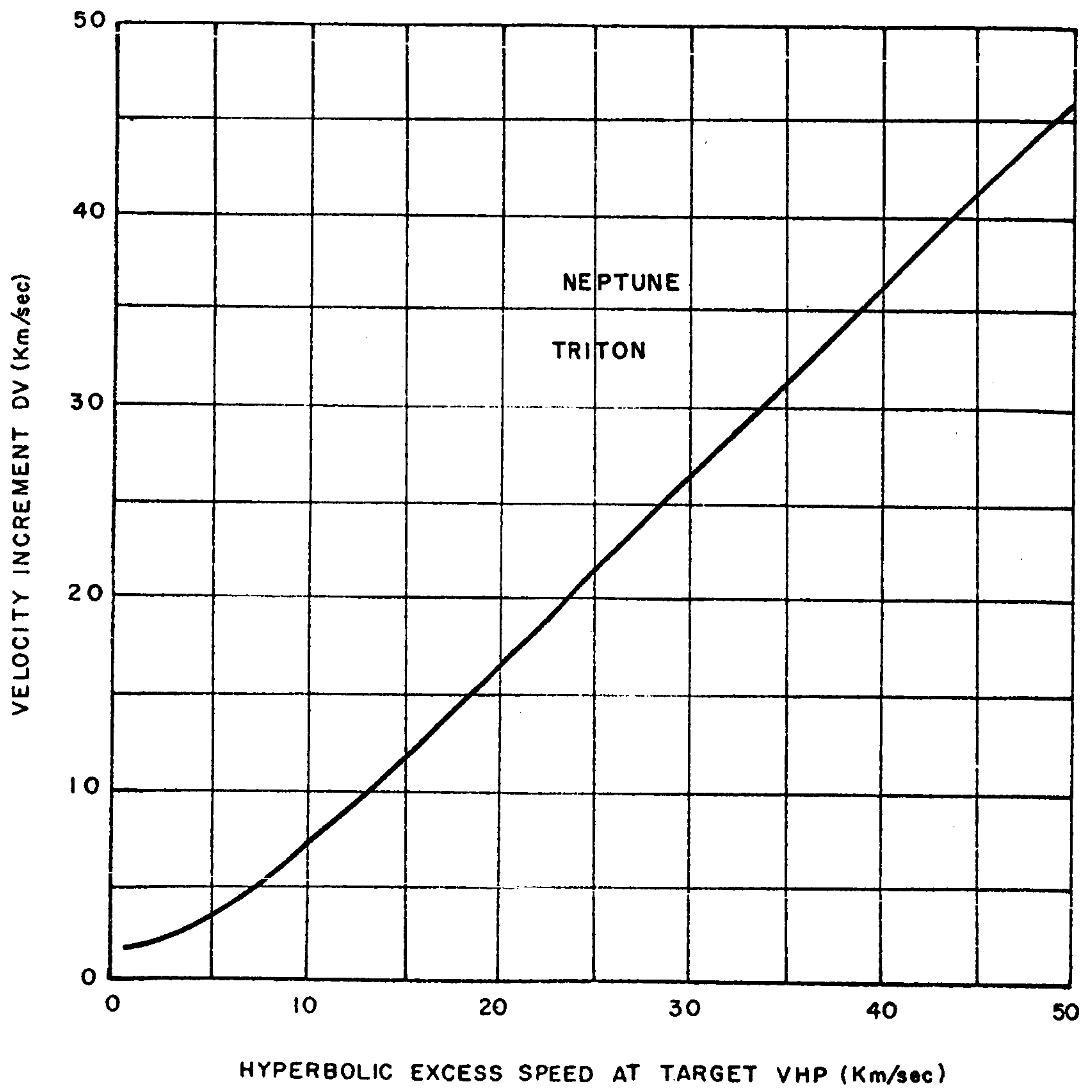


Figure 28 Velocity Increments to Transfer from Approach Hyperbolas to Capture Orbits Matching that of the Satellites: For Neptune Satellite 1 (Triton)

Table 1

## KEY PARAMETERS FOR MINIMUM ENERGY TRAJECTORIES[1] IN THE ECLIPTIC PLANE

| Target Distance from Sun (AU) | Launch Hyperbolic Excess Speed VHL (km/sec) | Ideal Velocity $\Delta V$ (ft/sec) | Time of Flight (days) | Earth-Sun-Target Angle at Spacecraft Arrival (degrees) | Communications Distance RC (AU) |
|---|---|---|---|---|---|
| 0.1 | 17.1 | 70,600 | 74 | 105 | 1.05 |
| 0.3 | 9.5 | 51,800 | 95 | 85 | 1.05 |
| 0.7 | 2.8 | 41,300 | 140 | 40 | 0.65 |
| 2.0 | 4.6 | 43,200 | 335 | 150 | 2.9 |
| 3.0 | 6.8 | 46,300 | 515 | 30 | 2.2 |
| 5.0 | 8.8 | 50,000 | 950 | 60 | 4.6 |
| 10.0 | 10.6 | 53,600 | 2350 | 20 | 9.1 |

1 There are small variations in these figures for different launch times due to the ellipticity of the Earth's orbit, since the Earth-Sun distance and Earth's orbital velocity vary slightly with the Earth's position in its orbit. These are essentially Hohmann transfers.

Table 2

PLANETARY ATMOSPHERIC DATA

$$\rho(Z) = \rho(o) e^{-\beta Z}$$

| Planet | Assumed* Surface Pressure (atm) | Assumed* Atmos. Temp. (°K) | Assumed* Atmos. Mole. Wt. (g/mole) | Assumed** Surface Grav. Acceler. (cm/sec$^2$) | Calculated $\rho(o)$ (g/cm$^3$) | Calculated $\beta$ (km$^{-1}$) | Calculated Altitude at Which $\rho(Z) = 5.37 \times 10^{-13}$ g/cm$^3$ the Density of Earth's Atmos. at 100 N.M. alt. (in km) | (in planetary radii) |
|---|---|---|---|---|---|---|---|---|
| Mercury | --- | --- | --- | --- | --- | --- | 0. | 1.0 |
| Venus | 10. | 600. | 30. | 843. | $6.07 \times 10^{-3}$ | 0.0507 | 456. | 1.074 |
| Mars | 0.01 | 200. | 32. | 401. | $1.94 \times 10^{-5}$ | 0.0772 | 225. | 1.068 |
| Jupiter | 2. | 150. | 3.3 | 2767. | $5.35 \times 10^{-4}$ | 0.0732 | 283. | 1.0040 |
| Saturn | 2. | 80. | 3.5 | 1274. | $1.06 \times 10^{-3}$ | 0.0670 | 319. | 1.0055 |
| Uranus | 9. | 75. | 3.5 | 958. | $5.10 \times 10^{-3}$ | 0.0537 | 427. | 1.017 |
| Neptune | 9. | 75. | 3.5 | 1122. | $5.10 \times 10^{-3}$ | 0.0630 | 364. | 1.010 |
| Pluto | --- | --- | --- | --- | --- | --- | --- | --- |

* Kuiper 1952; Spinrad 1963; Murray 1963; Sagan 1963; Kaplan 1964; Owen 1964.

** Ehricke 1960.

Table 3

PLANET DATA

| Planet | Gravitational Parameter * K ($km^3/sec^2$) | Equatorial Radius $R_o$ (km) | Semi-Major Axis of Orbit (AU) | Eccentricity of Orbit | Perihelion Distance (AU) | Aphelion Distance (AU) | Inclination of Orbit to Ecliptic ° ' " | Mean Orbital Velocity Earth = 1 | Period of Revolution (years) | Density Water = 1 | Mass ⊕ = 1 | Period of Rotation, ω h. m. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mercury | $2.168553 \times 10^4$ | 2,500 | 0.387099 | 0.2056259 | 0.307501 | 0.466697 | 7 0 14.2 | 1.607271 | 0.2411 | 5.00 | 0.0543 | |
| Venus | $3.247695 \times 10^5$ | 6,200 | 0.723332 | 0.0067935 | 0.718418 | 0.728246 | 3 23 39.1 | 1.175794 | 0.6156 | 4.90 | 0.8136 | |
| Earth | $3.986032 \times 10^5$ | 6,378 | 1.000000 | 0.0167272 | 0.983273 | 1.016727 | | 1.0 | 1.0 | 5.52 | 1.0 | 23 56.068 |
| Mars | $4.297780 \times 10^4$ | 3,310 | 1.523691 | 0.0933654 | 1.381431 | 1.665951 | 1 50 50.8 | 0.8068546 | 1.8822 | 4.20 | 0.1077 | 24 37.38 |
| Jupiter | $1.267106 \times 10^8$ | 69,880 | 5.202803 | 0.0484305 | 4.950829 | 5.454777 | 1 18 19.9 | 0.4384109 | 11.86 | 1.33 | 318.35 | 9 50.5 |
| Saturn | $3.791870 \times 10^7$ | 57,550 | 9.538843 | 0.0556922 | 9.007604 | 10.070082 | 2 29 42.2 | 0.3237816 | 29.46 | 0.71 | 95.3 | 10 2 |
| Uranus | $5.803292 \times 10^6$ | 25,500 | 19.181973 | 0.0472012 | 18.276561 | 20.087385 | 0 46 22.9 | 0.2283249 | 84.0 | 1.26 | 14.58 | 10 48 |
| Neptune | $7.026072 \times 10^6$ | 25,000 | 30.057707 | 0.0085724 | 29.800040 | 30.315374 | 1 46 26.5 | 0.1823988 | 164.8 | 1.61 | 17.26 | 15 48 |
| Pluto | $3.317886 \times 10^6$ | 7,000** | 39.51774 | 0.2486438 | 29.691899 | 49.343581 | 17 8 38.4 | 0.7590757 | 247.7 | | 0.8312 | |

* V. C. Clarke, Jr. (1962)

** Explanatory Supplement (1961)

All other data from Krafft A. Ehricke, (1960)

Earth's Mean Orbital Velocity = 29.77 km/sec

Earth Mass = $5.98 \times 10^{27}$ g

Table 4

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND MERCURY WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Mercury Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.17 | 0.25 | 0.34 | 0.52 | 0.67 |
| 5 | 2.86 | 3.47 | 3.85 | 4.35 | 4.60 |
| 10 | 7.48 | 8.31 | 8.77 | 9.32 | 9.59 |
| 15 | 12.34 | 13.25 | 13.74 | 14.31 | 14.59 |
| 25 | 23.09 | 23.21 | 23.72 | 24.31 | 24.59 |

Mercury Circular

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 1.03 | 0.80 | 0.72 | 0.73 | 0.79 |
| 5 | 3.72 | 4.02 | 4.24 | 4.55 | 4.72 |
| 10 | 8.34 | 8.85 | 9.16 | 9.53 | 9.71 |
| 15 | 13.20 | 13.80 | 14.13 | 14.52 | 14.71 |
| 25 | 23.09 | 23.75 | 24.10 | 24.51 | 24.71 |

Table 5

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND VENUS WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Venus Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.07 | 0.11 | 0.15 | 0.27 | 0.41 |
| 5 | 1.56 | 2.20 | 2.72 | 3.56 | 4.08 |
| 10 | 5.11 | 6.42 | 7.27 | 8.42 | 9.03 |
| 15 | 9.42 | 11.11 | 12.11 | 13.37 | 14.01 |
| 25 | 18.79 | 20.84 | 21.97 | 23.33 | 24.00 |

Venus Circular

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 2.19 | 1.45 | 1.10 | 0.77 | 0.71 |
| 5 | 3.68 | 3.45 | 3.67 | 4.07 | 4.38 |
| 10 | 7.23 | 7.76 | 8.22 | 8.93 | 9.33 |
| 15 | 11.54 | 12.45 | 13.06 | 13.88 | 14.31 |
| 25 | 20.91 | 22.18 | 22.92 | 23.84 | 24.30 |

Table 6

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND EARTH WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Earth Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.06 | 0.10 | 0.14 | 0.25 | 0.38 |
| 5 | 1.45 | 2.07 | 2.59 | 3.46 | 4.01 |
| 10 | 4.84 | 6.18 | 7.07 | 8.29 | 8.94 |
| 15 | 9.05 | 10.81 | 11.88 | 13.23 | 13.92 |
| 25 | 18.31 | 20.50 | 21.71 | 23.18 | 23.91 |

Earth Circular

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2.38 | 1.56 | 1.17 | 0.80 | 0.71 |
| 5 | 3.76 | 3.54 | 3.62 | 4.01 | 4.33 |
| 10 | 7.16 | 7.64 | 8.11 | 8.84 | 9.27 |
| 15 | 11.37 | 12.28 | 12.91 | 13.78 | 14.25 |
| 25 | 20.63 | 21.96 | 22.75 | 23.74 | 24.23 |

Table 7

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND MARS WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Mars Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.14 | 0.21 | 0.29 | 0.46 | 0.61 |
| 5 | 2.56 | 3.22 | 3.64 | 4.21 | 4.52 |
| 10 | 7.03 | 7.98 | 8.52 | 9.18 | 9.50 |
| 15 | 11.82 | 12.89 | 13.47 | 14.16 | 14.50 |
| 25 | 21.65 | 22.82 | 23.44 | 24.15 | 24.50 |
| Mars Circular | | | | | |
| 1 | 1.19 | 0.88 | 0.76 | 0.71 | 0.76 |
| 5 | 3.62 | 3.88 | 4.11 | 4.46 | 4.67 |
| 10 | 8.08 | 8.64 | 8.99 | 9.43 | 9.65 |
| 15 | 12.88 | 13.56 | 13.95 | 14.42 | 14.65 |
| 25 | 22.71 | 23.49 | 23.91 | 24.41 | 24.64 |

Table 8

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND JUPITER WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Jupiter Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.01 | 0.02 | 0.03 | 0.05 | 0.08 |
| 5 | 0.29 | 0.46 | 0.65 | 1.16 | 1.81 |
| 10 | 1.16 | 1.80 | 2.47 | 4.09 | 5.65 |
| 15 | 2.56 | 3.90 | 5.20 | 7.95 | 10.14 |
| 25 | 6.80 | 9.82 | 12.38 | 16.81 | 19.69 |

Jupiter Circular

| | | | | | |
|---|---|---|---|---|---|
| 1 | 12.48 | 7.91 | 5.60 | 3.03 | 1.85 |
| 5 | 12.76 | 8.35 | 6.22 | 4.14 | 3.57 |
| 10 | 13.63 | 9.68 | 8.04 | 7.07 | 7.42 |
| 15 | 15.04 | 11.78 | 10.78 | 10.93 | 11.91 |
| 25 | 19.27 | 17.70 | 17.96 | 19.80 | 21.46 |

Table 9

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND SATURN WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Saturn Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.02 | 0.03 | 0.04 | 0.08 | 0.14 |
| 5 | 0.48 | 0.75 | 1.04 | 1.78 | 2.55 |
| 10 | 1.88 | 2.83 | 3.74 | 5.60 | 7.01 |
| 15 | 4.06 | 5.87 | 7.41 | 10.07 | 11.80 |
| 25 | 10.16 | 13.57 | 16.03 | 19.61 | 21.63 |
| | | Saturn Circular | | | |
| 1 | 7.54 | 4.79 | 3.41 | 1.88 | 1.20 |
| 5 | 8.00 | 5.51 | 4.40 | 3.58 | 3.61 |
| 10 | 9.40 | 7.59 | 7.11 | 7.39 | 8.07 |
| 15 | 11.58 | 10.62 | 10.77 | 11.87 | 12.87 |
| 25 | 17.68 | 18.33 | 19.39 | 21.40 | 22.70 |

Table 10

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND URANUS WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Uranus Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.03 | 0.05 | 0.07 | 0.14 | 0.22 |
| 5 | 0.81 | 1.23 | 1.65 | 2.56 | 3.30 |
| 10 | 3.01 | 4.28 | 5.32 | 7.02 | 8.09 |
| 15 | 6.19 | 8.24 | 9.70 | 11.82 | 13.02 |
| 25 | 14.11 | 17.22 | 19.15 | 21.65 | 22.96 |
| | | | Uranus Circular | | |
| 1 | 4.45 | 2.85 | 2.05 | 1.19 | 0.85 |
| 5 | 6.23 | 4.03 | 3.63 | 3.61 | 3.93 |
| 10 | 7.43 | 7.07 | 7.29 | 8.08 | 8.72 |
| 15 | 10.61 | 11.03 | 11.68 | 12.88 | 13.64 |
| 25 | 18.53 | 20.01 | 21.12 | 22.71 | 23.58 |

Table 11

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND NEPTUNE WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Neptune Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.03 | 0.05 | 0.07 | 0.12 | 0.20 |
| 5 | 0.73 | 1.12 | 1.51 | 2.40 | 3.16 |
| 10 | 2.76 | 3.97 | 5.00 | 6.77 | 7.91 |
| 15 | 5.73 | 7.77 | 9.27 | 11.52 | 12.82 |
| 25 | 13.34 | 16.55 | 18.60 | 21.31 | 22.74 |
| | | | Neptune Circular | | |
| 1 | 4.94 | 3.15 | 2.26 | 1.31 | 0.90 |
| 5 | 5.64 | 4.23 | 3.71 | 3.57 | 3.86 |
| 10 | 7.67 | 7.08 | 7.20 | 7.94 | 8.60 |
| 15 | 10.64 | 10.87 | 11.47 | 12.69 | 13.51 |
| 25 | 18.25 | 19.66 | 20.80 | 22.49 | 23.44 |

Table 12

VELOCITY INCREMENT TO TRANSFER INTO PARABOLIC OR CIRCULAR ORBITS AROUND PLUTO WITH PERIGEES AT 2, 5, 10, 35 AND 100 RADII FROM THE PLANET CENTER

Pluto Parabolic

| VHP (km/sec) | DV (km/sec) $R_p$ = 2 planet radii | DV (km/sec) $R_p$ = 5 planet radii | DV (km/sec) $R_p$ = 10 planet radii | DV (km/sec) $R_p$ = 35 planet radii | DV (km/sec) $R_p$ = 100 planet radii |
|---|---|---|---|---|---|
| 1 | 0.07 | 0.11 | 1.16 | 0.28 | 0.42 |
| 5 | 1.62 | 2.28 | 2.79 | 3.62 | 4.12 |
| 10 | 5.26 | 6.55 | 7.38 | 8.49 | 9.07 |
| 15 | 9.62 | 11.26 | 12.23 | 13.44 | 14.06 |
| 25 | 19.05 | 21.02 | 22.11 | 23.41 | 24.05 |
| | | | Pluto Circular | | |
| 1 | 2.09 | 1.39 | 1.06 | 0.76 | 0.71 |
| 5 | 3.64 | 3.55 | 3.69 | 4.10 | 4.41 |
| 10 | 7.27 | 7.83 | 8.29 | 8.97 | 9.36 |
| 15 | 11.64 | 12.54 | 13.14 | 13.93 | 14.34 |
| 25 | 21.06 | 22.30 | 23.01 | 23.89 | 24.33 |

Table 13

ORBITAL PERIODS (IN DAYS) FOR CIRCULAR ORBITS AT VARIOUS PLANET RADII FROM THE PLANET CENTERS

| | $R_p = 2$ | $R_p = 3$ | $R_p = 10$ | $R_p = 35$ | $R_p = 100$ | $R_p = 200$ |
|---|---|---|---|---|---|---|
| Mercury | 0.17 | 0.32 | 1.95 | 12.8 | 61.7 | 174. |
| Venus | 0.18 | 0.32 | 1.97 | 12.9 | 62.3 | 176. |
| Earth | 0.17 | 0.30 | 1.86 | 12.2 | 58.7 | 166. |
| Mars | 0.19 | 0.35 | 2.11 | 13.8 | 66.8 | 189. |
| Jupiter | 0.34 | 0.62 | 3.77 | 24.7 | 119. | 338. |
| Saturn | 0.46 | 0.85 | 5.16 | 33.8 | 163. | 461. |
| Uranus | 0.35 | 0.64 | 3.89 | 25.5 | 123. | 348. |
| Neptune | 0.31 | 0.56 | 3.43 | 22.5 | 108. | 306. |
| Pluto | 0.21 | 0.38 | 2.34 | 15.4 | 73.9 | 209. |

Table 14

## SATELLITE DATA

(All data from Russell, Dugan and Stewart, 1945)

| | Name | Mean Dist. in Equatorial Radii of Planet | Sidereal Period | Eccentricity | Diameter (km) | Mass Moon = 1 |
|---|---|---|---|---|---|---|
| | Earth | | | | | |
| | Moon | 60.267 | $27^d\ 7.7^h$ | 0.05490 | 3476 | 1.00 * |
| | Mars | | | | | |
| 1 | Phobos | 2.79 | $7.6^h$ | 0.021 | 15 ? | |
| 2 | Deimos | 6.93 | $1^d\ 6.3^h$ | 0.003 | 8 ? | |
| | Jupiter | | | | | |
| 5 | Nameless | 2.540 | $11.9^h$ | 0.0028 | 150 ? | |
| 1 | Io | 5.905 | $1^d\ 18.4^h$ | 0.0000 | 3730 | 0.99 |
| 2 | Europa | 9.401 | $3^d\ 13.2^h$ | 0.0003 | 3150 | 0.64 |
| 3 | Ganymede | 14.995 | $7^d\ 3.7^h$ | 0.0015 | 5150 | 2.11 |
| 4 | Callisto | 26.379 | $16^d\ 16.5^h$ | 0.0075 | 5180 | 1.32 |
| 6 | Nameless | 161 | $250.7^d$ | 0.155 | 120 ? | |
| 7 | Nameless | 165 | $260.0^d$ | 0.207 | 50 ? | |
| 10 | Nameless | 165 | $260^d$ | 0.08 | 20 ? | |
| 8 | Nameless | 330 | $739^d$ | 0.378 | 50 ? | |
| 9 | Nameless | 332 | $758^d$ | 0.27 | 22 ? | |
| 11 | Nameless | 315 | $692^d$ | 0.21 | 25 ? | |
| 12 | Nameless ** | | | | | |
| | Saturn | | | | | |
| 7 | Mimas | 3.11 | $22.6^h$ | 0.0201 | 450 ? | $5.16 \times 10^{-4}$ |
| 6 | Enceladus | 3.99 | $1^d\ 8.9^h$ | 0.0044 | 500 ? | $1.17 \times 10^{-3}$ |
| 5 | Tethys | 4.94 | $1^d\ 21.3^h$ | 0.0000 | 1100 ? | $8.8 \times 10^{-2}$ |
| 4 | Dione | 6.33 | $2^d\ 17.7^h$ | 0.0022 | 1100 ? | 0.014 |
| 2 | Rhea | 8.84 | $4^d\ 12.4^h$ | 0.0010 | 1600 ? | 0.03: |
| 1 | Titan | 20.48 | $15^d\ 22.7^h$ | 0.0289 | 4200 | 1.92 |
| 8 | Hyperion | 24.82 | $21^d\ 6.6^h$ | 0.1043 | 400 ? | $< 6 \times 10^{-4}$ |
| 3 | Iapetus | 59.68 | $79^d\ 7.9^h$ | 0.0283 | 1300 ? | 0.019 |
| 9 | Phoebe | 216.8 | $550.44^d$ | 0.166 | 300 ? | |

* Moon Mass = $7.33 \times 10^{25}$ g

** K. A. Ehricke (1960)

Table 14 (Cont'd)

| Name | Mean Dist. in Equatorial Radii of Planet | Sidereal Period | Eccentricity | Diameter (km) | Mass Moon = 1 |
|---|---|---|---|---|---|
| Uranus | | | | | |
| 3 Ariel | 7.35 | $2^d 12.5^h$ | 0.007 | 500? | |
| 4 Umbriel | 10.2 | $4^d 3.4^h$ | 0.008 | 400? | |
| 1 Titania | 16.8 | $8^d 16.9^h$ | 0.023 | 1000? | |
| 2 Oberon | 22.4 | $13^d 11.1^h$ | 0.010 | 900? | |
| 5 Nameless * | | | | | |
| Neptune | | | | | |
| 1 Triton | 14.2 | $5^d 21.0^h$ | 0.000 | 4500: | 1.8 |
| 2 Nereid * | | | | | |

* K. A. Ehricke (1961)